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AgRISTARS

A Joint Program for
Agriculture and
Resources Inventory
Surveys Through
Aerospace
Remote Sensing

Inventory Technology
Development

April 1983

THE 1980 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT FINAL REPORT

VOLUME I

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National Aeronautics and Space Administration

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16. Abstract

This report presents the results from the U.S./Canada Wheat and Barley Exploratory Experiment which was completed during FY 1980. The results indicate that the new crop identification procedures performed well for spring small grains and that they are conducive to automation. The performance of the machine processing techniques shows a significant improvement over previously evaluated technology. However, the crop calendars will require additional development and refinements prior to integration into automated area estimation technology.

The evaluation has shown the integrated technology to be capable of producing accurate and consistent spring small grains proportion estimates. However, barley proportion estimation technology was not satisfactorily evaluated. Landsat sample segment data were not available for high-density barley of primary importance in foreign regions. The low-density segments examined were judged not to give indicative or unequivocal results.

It is concluded that, generally, the spring small grains technology is ready for evaluation in a pilot experiment focusing on sensitivity analyses to a variety of agricultural and meteorological conditions representative of the global environment. It is further concluded that a strong potential exists for establishing a highly efficient technology for spring small grains.

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FINAL REPORT VOLUME I

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This report describes the 1980 U.S./Canada Wheat and Barley Exploratory Experiment of the Inventory Technology Development Department within the AgRISTARS program.

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For

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

April 1983

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PREFACE

The Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing is a program of research, development, evaluation, and application of aerospace remote sensing for agricultural resources. This program is a cooperative effort of the National Aeronautics and Space Administration, the U.S. Departments of Agriculture, Commerce, and the Interior, and the U.S. Agency for International Development.

The work which is the subject of this document was performed by the Earth Resources Applications Division, Space and Life Sciences Directorate, Lyndon B. Johnson Space Center, National Aeronautics and Space Administration and the Lockheed Engineering and Management Services Company, Inc. Tasks performed by Lockheed were accomplished under Contract NAS 9-15800.

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ACRONYMS

AgRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
AID	U.S. Agency for International Development
APU	Agrophysical unit
CLASSY	A clustering algorithm
ERIM	Environmental Research Institute of Michigan
FCPF	Foreign Commodity Production Forecasting
FY	Fiscal Year
GSFC	Goddard Space Flight Center
ISOCLS	Iterative Self-Organizing Clustering System
ITD	Inventory Technology Department
JSC	Lyndon B. Johnson Space Center
LACIE	Large Area Crop Inventory Experiment
MSE	Mean square error
MSS	Multispectral scanner
NASA	National Aeronautics and Space Administration
P1	Procedure 1
pixel	Picture element
OPS	Operations
QA	Quality assurance
TY	Transition Year
SRS	Statistical Reporting Service
SSG	Spring small grains
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of Interior
USNGP	U.S. Northern Great Plains

EXECUTIVE SUMMARY

The 1980 U.S./Canada Wheat and Barley Exploratory Experiment was designed to further develop state-of-the-art area estimation technology and test it in a foreign similar environment.

Research, which was performed prior to the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) project, had identified technical issues (1) in the reliability and efficiency of estimating spring small grains in the U.S. Northern Great Plains and Canada and (2) in the separation of spring wheat and spring barley by using remote sensing data. Approaches had been developed that provided potential improvement for solving the identified technical issues. Thus, the 1980 U.S./Canada Wheat and Barley Exploratory Experiment was oriented toward developing and testing these approaches for potential further testing and development leading to foreign application. Developmental activities were initiated to produce an advanced technology which was not only accurate but also efficient and objective. The improvements were directed toward developing an automated area estimation technology, with minimal analyst interaction, as one component of a foreign commodity production forecasting system.

In response to these objectives, the Inventory Technology Development (ITD)* and Supporting Research projects developed improved crop identification procedures, machine processing techniques, and crop calendar models. The ITD project integrated this technology into the area estimation system and implemented the exploratory test and evaluation. The exploratory evaluation was conducted in order to better understand the performance of this newly developed technology before proceeding to a pilot experiment for evaluation under a larger and more varied set of agricultural and environmental conditions.

*The ITD was formerly called the Foreign Commodity Production Forecasting (FCPF) project.

The techniques developed and integrated into the ITD developmental area estimation component for evaluation during the 1980 U.S./Canada Wheat and Barley Exploratory Experiment were: (1) objective crop identification procedures designed to produce consistent and accurate spring small grains identification/labeling results, (2) advanced machine processing techniques developed to improve the estimation of crop area within the sample segments (5 x 6 n.mi. areas), and (3) recently developed crop calendar models designed to provide improved estimates of the crop development stages for wheat and barley.

The results of the experiment indicated that the new crop identification procedures performed well for spring small grains and they are conducive to automation. The performance of the machine processing techniques shows a significant improvement over previously evaluated technology. However, the crop calendars will require additional development and refinements prior to integration into automated area estimation technology.

The evaluation has shown that the integrated technology is capable of producing accurate and consistent spring small grains proportion estimates. However, barley proportion estimation technology was not satisfactorily evaluated. Landsat sample segment data were not available for the high-density barley which is of primary importance in foreign regions. The low-density segments examined were judged as not giving indicative or unequivocal results.

It is concluded that, generally, the spring small grains technology is ready for evaluation in a pilot experiment focusing on sensitivity analyses to a variety of agricultural and meteorological conditions representative of the global environment. It is further concluded that a strong potential exists for establishing a highly efficient technology for spring small grains.

The information in this Executive Summary is based on the following document:

Payne, R. W., 1980 U.S./Canada Wheat and Barley Exploratory Experiment Summary Report, NASA/JSC-17406, LEMSCO-16921, July 1981.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this report is to present the results from the 1980 U.S./Canada Wheat and Barley Exploratory Experiment.

The developmental activities and experiments reported in this document cover activities of the Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) Inventory Technology Development (ITD)* project. These activities include component-level exploratory development, integration and testing of crop identification procedures, alternative computer classification techniques, and candidate crop development stage models. Remote sensing research related to wheat and barley has also been conducted by the Environmental Research Institute of Michigan (ERIM) for the AgRISTARS Supporting Research project and is reported elsewhere (ref. 1).

1.2 AgRISTARS PROGRAM

The AgRISTARS program is a 6-year program of research, development, and evaluation of the application of aerospace remote sensing to monitoring agricultural resources. The program began in fiscal year (FY) 1980. The AgRISTARS program is a cooperative effort of the National Aeronautics and Space Administration (NASA), the U.S. Departments of Agriculture, Commerce, and the Interior (USDA, USDC, and USDI), and the U.S. Agency for International Development (AID). The goal of this program is to determine the usefulness, cost, and extent to which aerospace remote sensing data can be used by the USDA to improve the objectivity, reliability, and timeliness of information required to carry out USDA missions (ref. 2).

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*The ITD project was formerly called the Foreign Commodity Production Forecasting (FCPF) project.

1.3 ITD PROJECT

An objective of the ITD project is to develop and test procedures for using aerospace remote sensing technology to provide more objective, timely, and reliable crop production forecasting in foreign areas. To develop technology for use in foreign areas, the ITD project builds upon existing remote sensing technology and extends this technology to additional crops and regions.

During FY 1980, two exploratory experiments were performed using U.S. data to develop and evaluate techniques. These experiments were the U.S./Canada Wheat and Barley Exploratory Experiment (ref. 3) and the U.S. Corn/Soybean Exploratory Experiment (ref. 4). The results from the U.S./Canada Wheat and Barley Exploratory Experiment are presented in this report (refs. 3 and 5).

Conclusions, results, and technical approaches in this report are described more fully in the addenda to this report (the 1980 U.S./Canada Wheat and Barley Exploratory Experiment Final Report - Addenda, Volume II).

1.4 U.S./CANADA WHEAT AND BARLEY EXPLORATORY EXPERIMENT

The overall objective of the 1980 U.S./Canada Wheat and Barley Exploratory Experiment was to develop, test, and evaluate state-of-the-art technology for spring small grains, spring wheat, and barley in order to establish a basis for further development of the estimation technology to be applied in foreign regions, specifically the U.S.S.R. and, indirectly, Australia and Argentina. For this exploratory experiment, the technical emphasis was:

a. To develop accurate and objective crop identification/labeling techniques (ref. 5).

b. To develop a machine processing technology with improved performance characteristics (ref. 6).

c. To develop alternative crop calendar/crop development stage models for making improved estimates of wheat and barley development (ref. 7).

2. EXPERIMENT DESCRIPTION

Three tests were performed as part of the U.S./Canada Wheat and Barley Exploratory Experiment (ref. 3). The first test was the labeling procedures; the second was the evaluation of machine processing/classification technology; and the third was the crop calendar/crop development stage models test. Figure 2-1 is the functional flow of a conceptual system which has these components incorporated into it.

2.1 LABELING PROCEDURES TEST - SUMMARY DESCRIPTION

The labeling procedures test was designed to test and evaluate a newly developed objective labeling procedure (SSG-1). The test was conducted in two phases.

a. Phase 1 - A shakedown test using six 1978 segments

b. Phase 2 - An expanded test using 35 segments from a different crop year (1979)

Locations of the segments used in the test are shown in figures 2-2 and 2-3. The objectives of this test were:

a. To determine the accuracy and objectivity of the newly developed spring small grains (SSG) labeling procedure.

b. To determine the accuracy of the barley estimation technology.

In both phases of the test, an objective labeling procedure[1] was used to label Landsat pixels (picture elements) in each segment. Input data to the new procedure consisted of Landsat multispectral scanner data, crop calendar information, and ancillary agronomic/meteorological data. (An example of the crop calendar information used in the procedure is shown in figure 2-4.)

[1]Development of the Enhanced Baseline Spring Small Grains Procedure (Reformatted Labeling Procedure). Lockheed Dept. 644-1472, Dec. 1979 (unpublished).

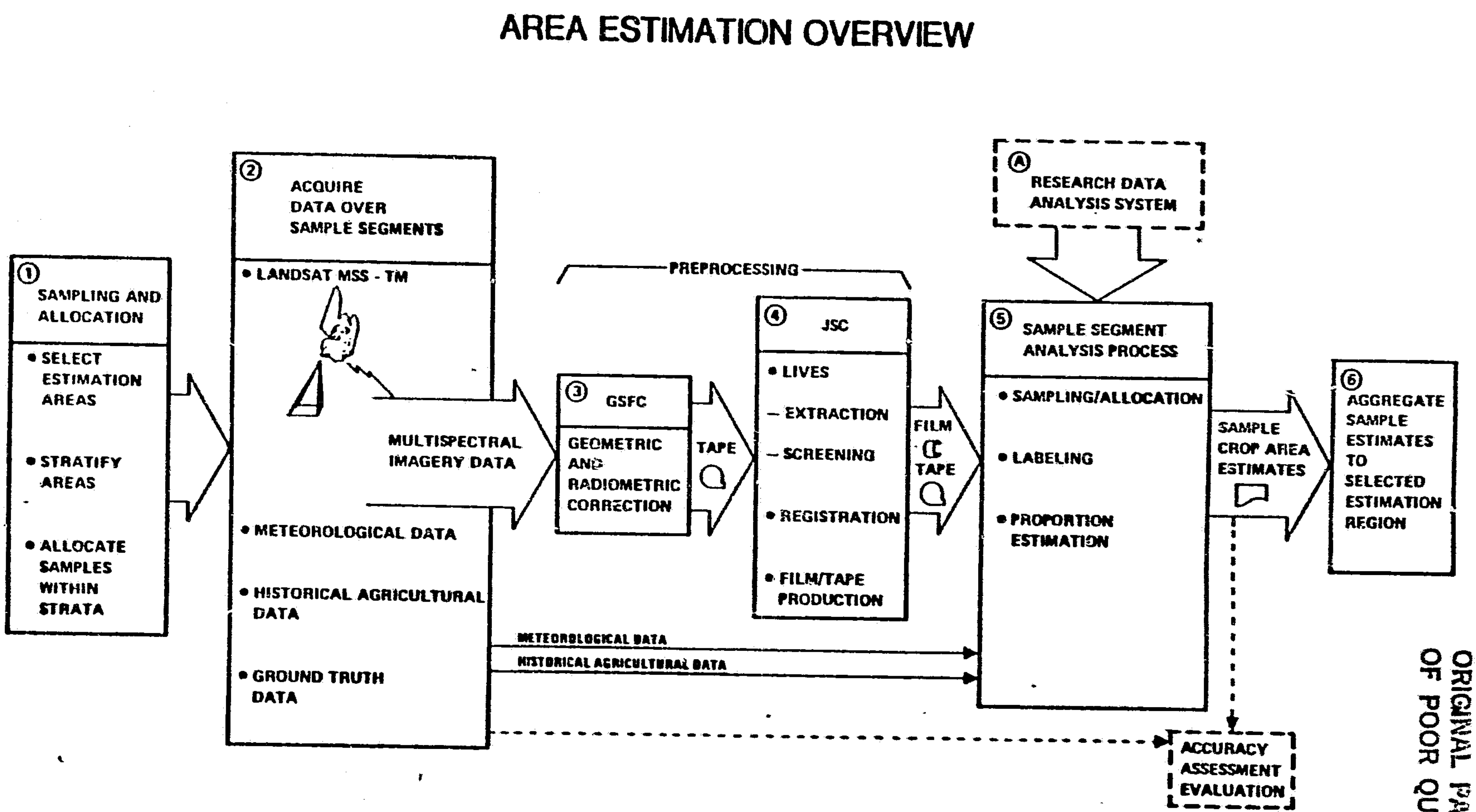

Figure 2-1.- A functional flow of the iTD area estimation approach.

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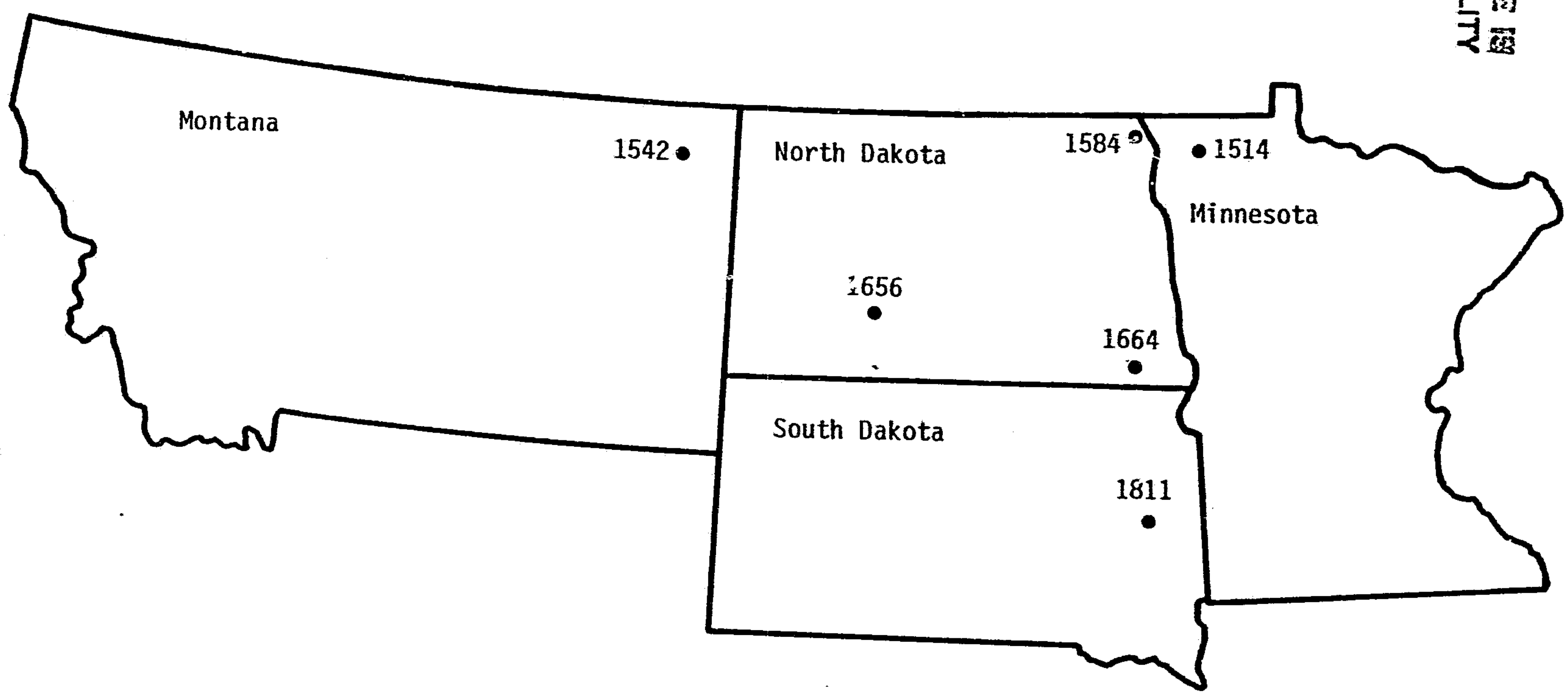

Figure 2-2.- 1978 segment locations for the Phase 1 labeling procedures shakedown test.

1979 SEGMENTS

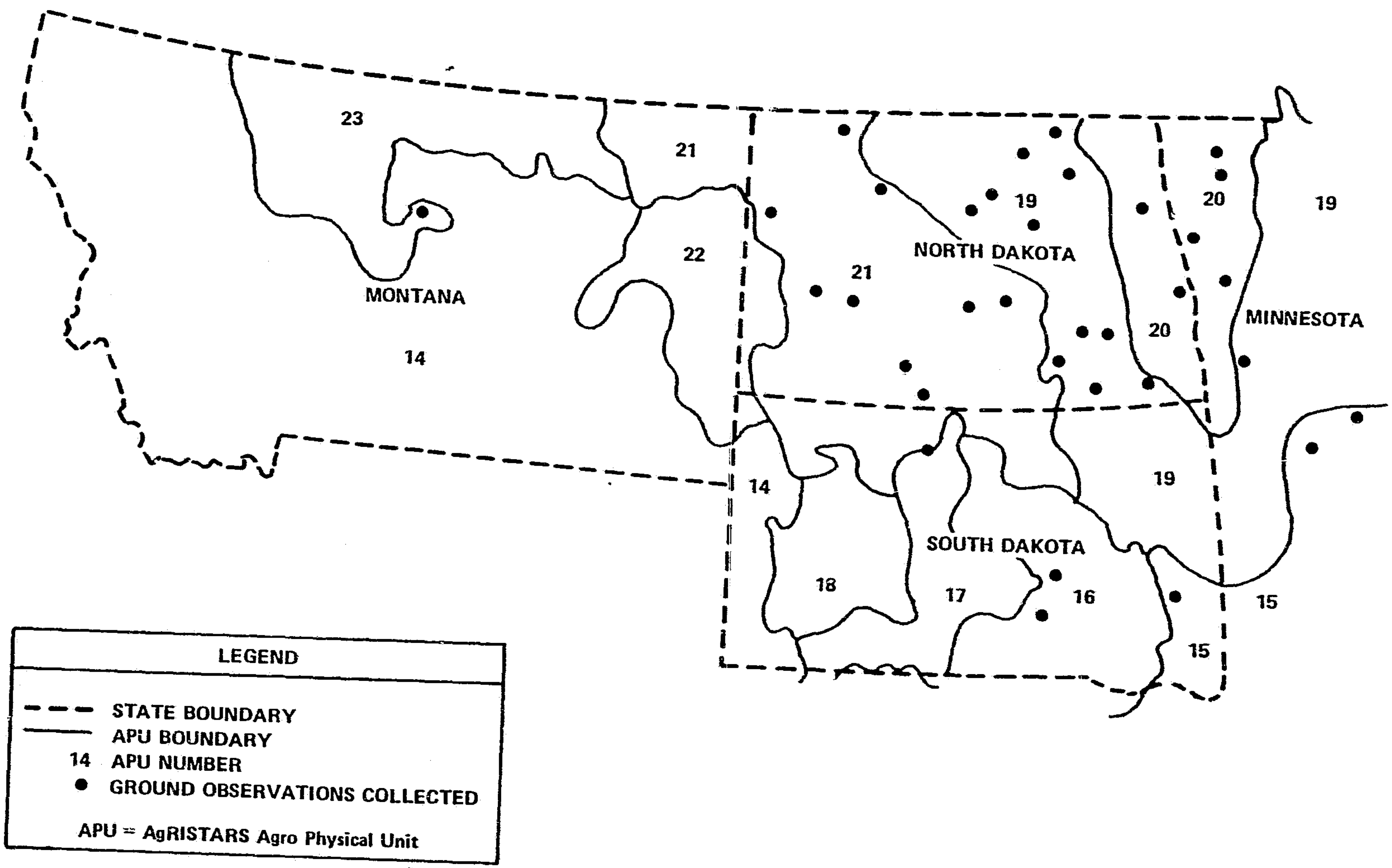

Figure 2-3.- Segment locations for the Phase 2 1979 Landsat data.

Area UNITED STATES

Pol/Sub NORTH DAKOTA

Date 4 DECEMBER 1979

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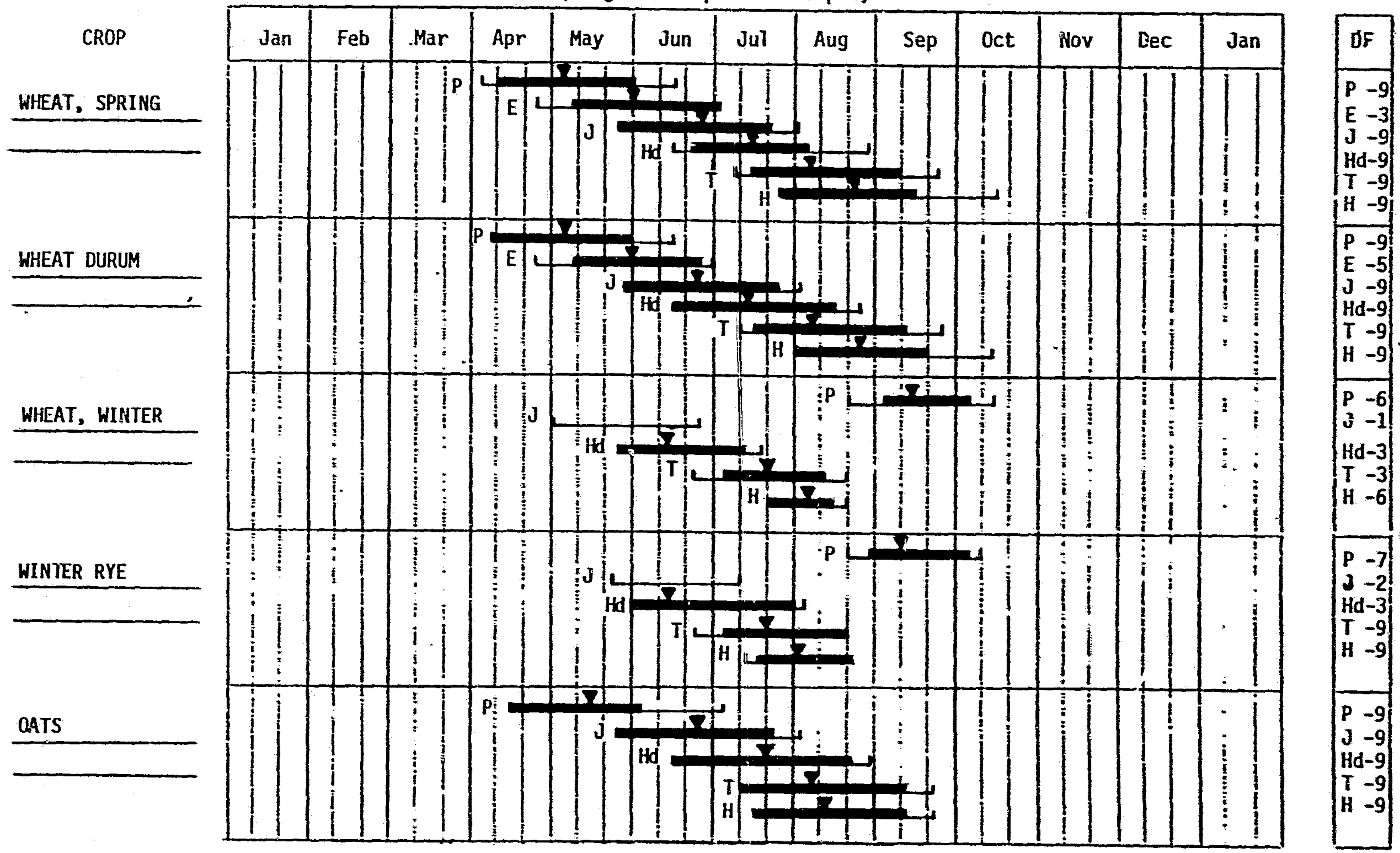
CROP CALENDAR

(Stage Development Timespan)



Sources: Field and Seed Crops Usual Planting and Harvest Dates. Agriculture Handbook No. 283, USDA/ESCS; also published and unpublished USDA/ESCS statistics and state agriculture statistics.

Figure 2-4.- North Dakota statewide historical crop calendar (ref. 8).

Area UNITED STATES

Pol/Sub NORTH DAKOTA

CROP CALENDAR

(Stage Development Timespan)

Date 4 DECEMBER 1979

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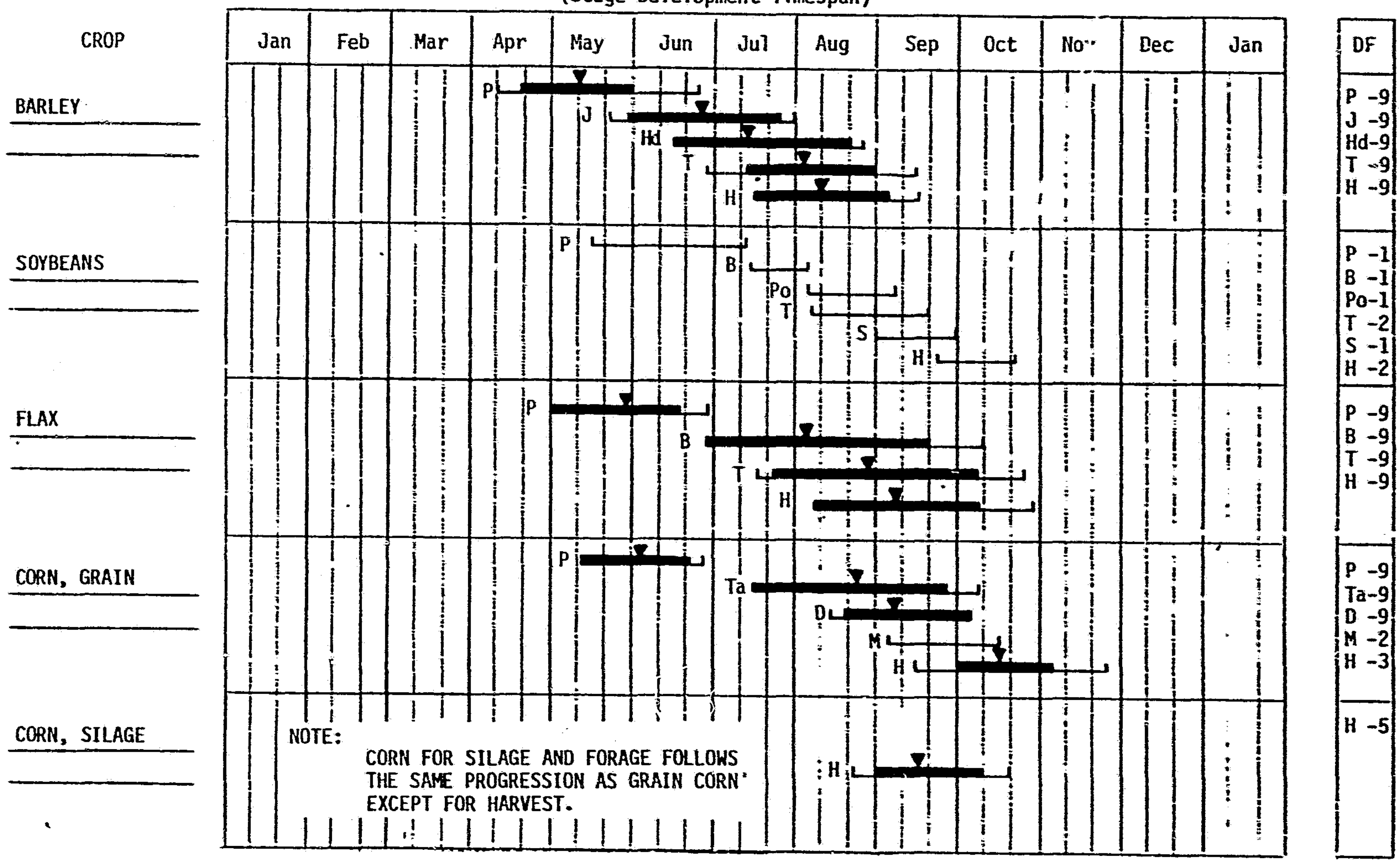

Figure 2-4.- Continued.

Area UNITED STATES

Date 4 DECEMBER 1979

Pol/Sub NORTH DAKOTA

Page 3 of 5

CROP CALENDAR

(Stage Development Timespan)

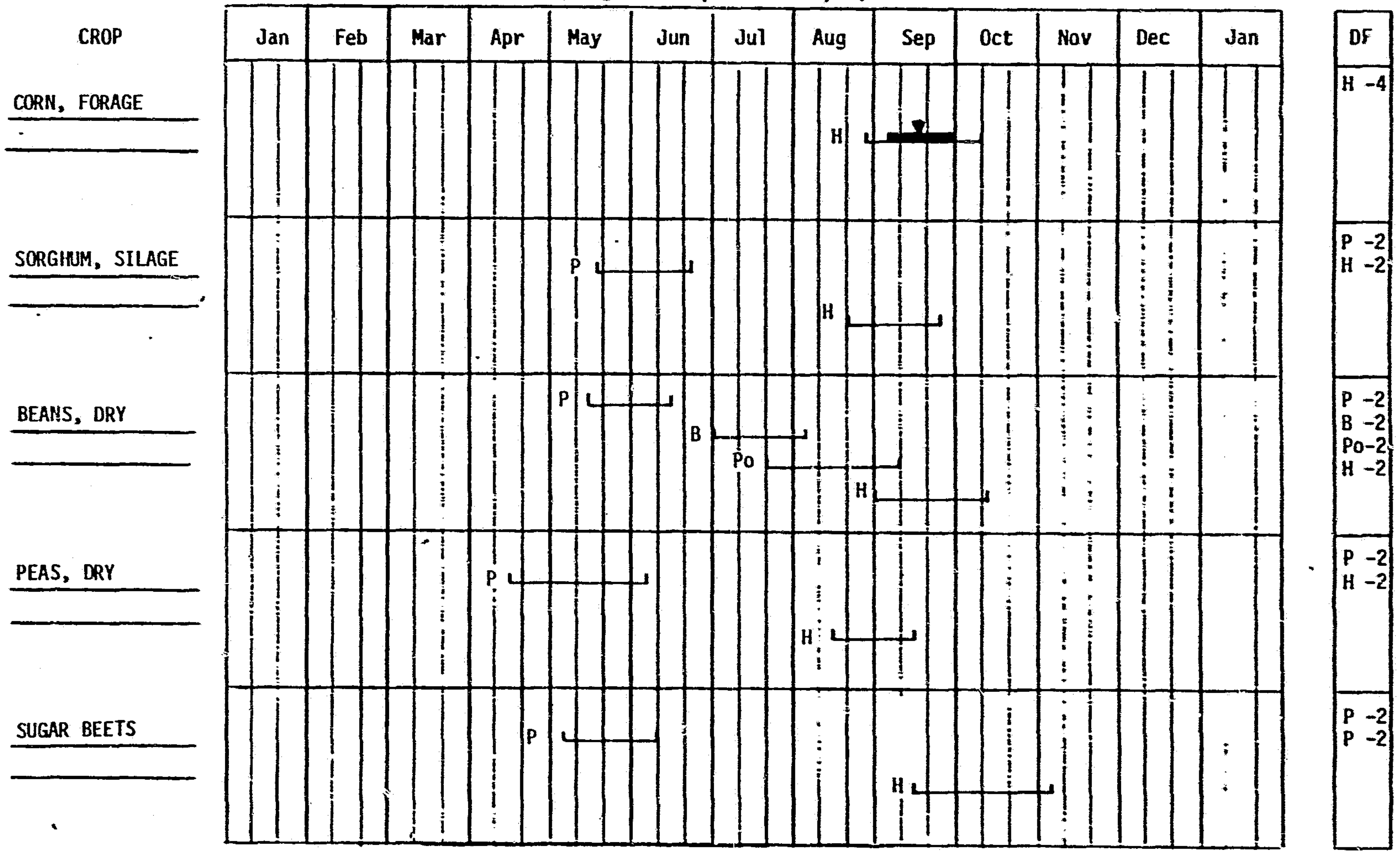

Figure 2-4.- Continued.

Area UNITED STATES

Pol/Sub NORTH DAKOTA

Date: 4 DECEMBER 1979

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CROP CALENDAR

(Stage Development Timespan)

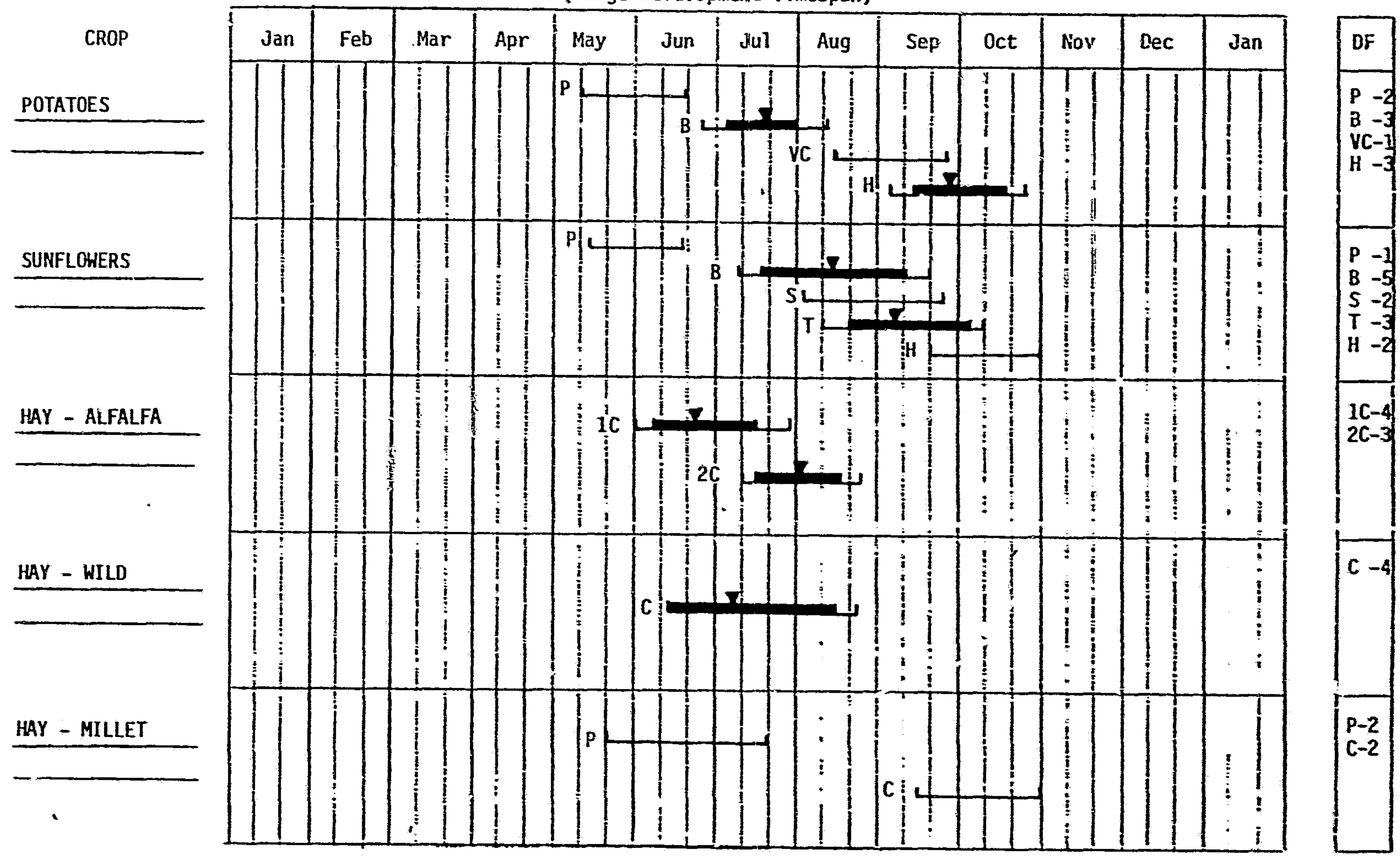

Figure 2-4.- Continued.

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Area UNITED STATES

Pol/Sub NORTH DAKOTA

Date 4 DECEMBER 1979

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CROP CALENDAR

(Stage Development Timespan)

CROP	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	DF
SEED CROP ALFALFA									H					H -2
SEED CROP SWEET CLOVER									H					H -2
SEED CROP KENTUCKY BLUEGRASS						H								H -2
SEED CROP CRESTED WHEAT GRASS							H							H -2

Figure 2-4.- Concluded.

The new procedure is designed to provide increasingly detailed labeling information at each step using a tree-structured decision logic (fig. 2-5). The first step consists of a labeling logic which is used to separate the pixels into cropland and noncropland. The pixels labeled cropland in the first step are separated into spring small grains and other crops in the second step. In the third step, Landsat spectral aids are used for separating the spring small grains into barley and other spring small grains.

The segments in the labeling procedure test were processed, independently, by two analysts in order to evaluate the repeatability and objectivity of the procedure. The evaluations were performed by comparing all labeling results to the segment ground-truth inventories. An error characterization study was performed to determine if any changes to the new labeling procedure were required to improve the objectivity or accuracy.

2.1.1 OBJECTIVE LABELING PROCEDURE - BACKGROUND AND DISCUSSION

The objective reformatted spring small grains labeling procedure (SSG-1) reduces the labeling decisions to a series of steps. These steps, when executed in an objective manner, allow analysts with limited experience to follow the procedure and arrive at crop identification labels with consistency. The development and description of this procedure are detailed in reference 9.

The U.S./Canada Wheat and Barley Exploratory Experiment (ref. 3) was designed to evaluate the new objective procedure (ref. 5). Phase 1 (shakedown test) was completed in the second quarter of FY 1980. Following a critical examination of the shakedown test results, refinements and modifications were made to the new objective reformatted spring small grains labeling procedure in preparation for additional testing which is Phase 2 (ref. 9). Two of these modifications are worthy of note:

a. A method for utilizing alternate dots was incorporated into the objective reformatted procedure in order to increase dot purity.

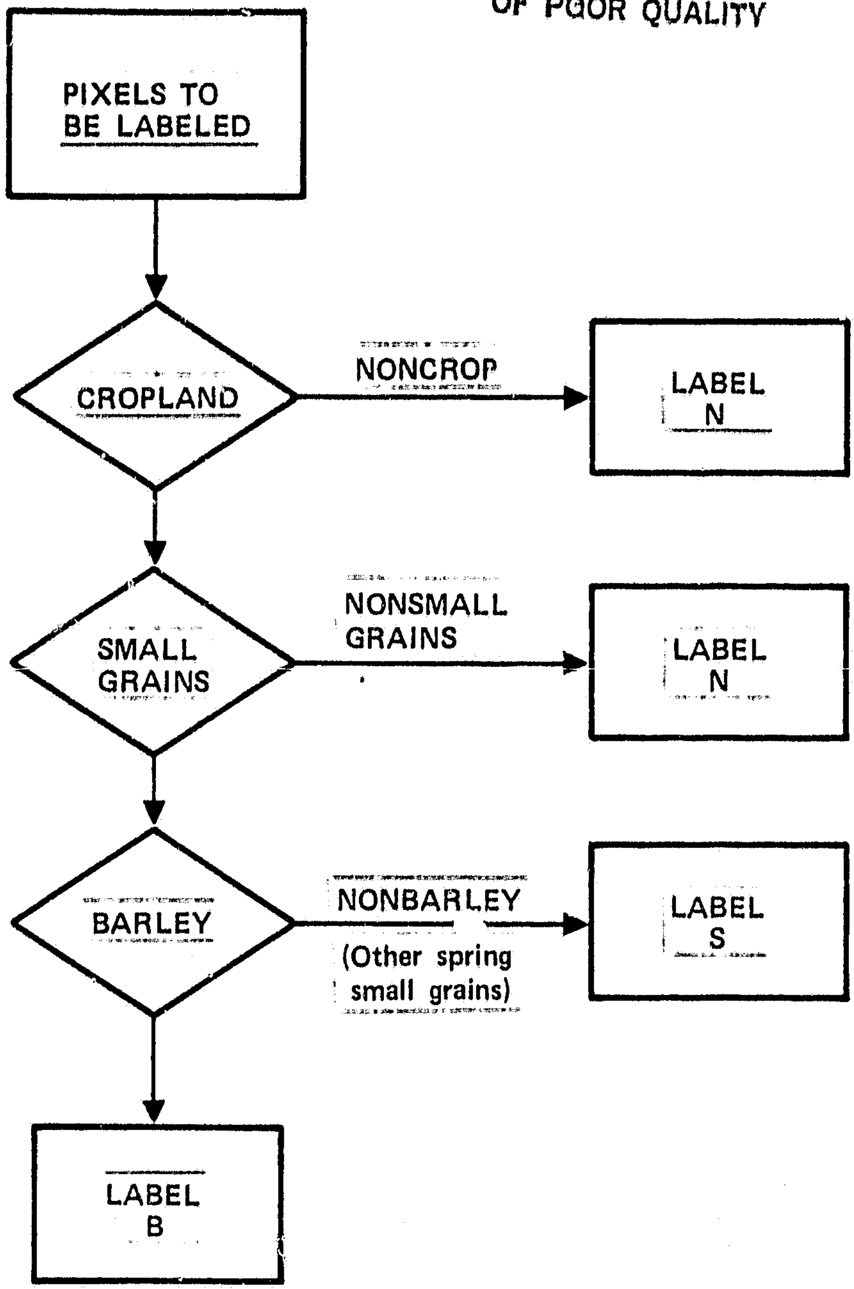

Figure 2-5.- The major steps in the reformatted objective labeling logic which leads to identification of barley and other spring small grains.

b. Current-year crop growth stage model results and statewide historical crop calendars were incorporated into the procedure. (An example of a statewide historical crop calendar is given in figure 2-4.)

The expanded tests (Phase 2, Parts 1 and 2) of the experiment began in the third quarter of FY 1980, using the new reformatted procedure (SSG-1) described in reference 9. Phase 2, Part 1, consisted of a processing of the segments using the older integrated procedure SSG-0 for comparison with the objective reformatted procedure. SSG-0 was developed during the Large Area Crop Inventory Experiment (LACIE) Transition Year (TY) [ref. 10]. The earlier integrated approach to labeling takes advantage of an analyst's experience and intuition. It was a learning experience, a necessary precursor to the eventual development of more objective labeling methodology. A generalized functional flow of the interated procedure is shown in figure 2-6(a).

For the integrated approach, a given segment was manually processed using the detailed analysis procedures developed during the LACIE and LACIE TY projects. This consisted of a team concept to labeling and crop signature review. The crop signatures and labels are then further reviewed by a quality assurance (QA) function. Finally, the segments are passed through a verification component that evaluates the estimates, in conjunction with other broad-level data, for trend analysis and problem detection/solving before being released for aggregation. Confidence levels using the integrated approach are directly related to the available Landsat acquisitions during the growing season. Figure 2-6(b) describes the confidence levels, from high to very low,-based on acquisitions used throughout the growing season for the analysis.

2.1.2 HISTORICAL DEVELOPMENT OF THE LABELING PROCEDURES

In support of the acreage estimation processes of the LACIE (ref. 11), agricultural analysts have relied on temporal analysis of Landsat data (ref. 12) to identify specific crops. Although the accuracy of identification was sufficient to provide estimates which met the goals of the experiment, consistent results between analysts were difficult to obtain without an intricate system.

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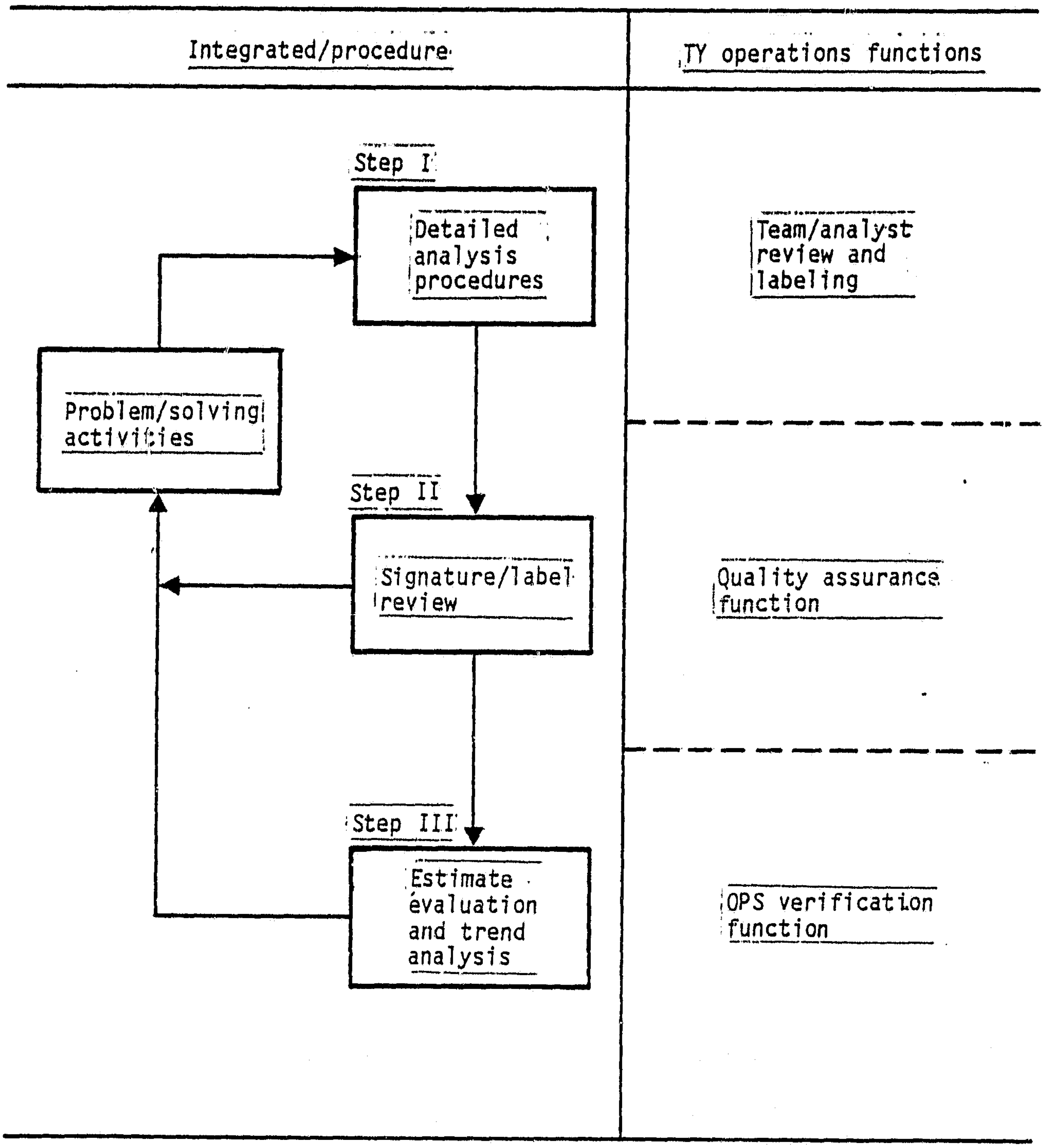

Figure 2-6(a).- Integrated analysis generalized functional flow (original procedure).

Confidence level	Criteria description
High	An acquisition during each of four analysis windows: 1. Preplant to emergence 2. Full ground cover 3. Ripening/ripe 4. Harvest to postharvest Spring small grains dominant crop Medium to large fields Prior years' Landsat imagery
Medium	An acquisition during three of four analysis windows Previous year's Landsat data
Low	An acquisition in only two of four analysis windows Previous year's Landsat data
Very low	An acquisition in only one or two of four analysis windows Absence of previous year's Landsat data

Figure 2-6(b).- Confidence-level criteria for the integrated procedure.

of quality assurance and teamwork. Clearly, a more objective procedure was needed.

Subsequent to the LACIE, developmental efforts were directed toward the expansion of the crop identification procedures to include other crops in addition to wheat, the principal crop of interest in the LACIE. The other crops initially selected for emphasis were corn and soybeans, with the U.S. Corn Belt as the primary area of concern.

The procedure (refs. 13 and 14) resulting from this developmental effort utilized decision-tree methodology and was designed to reduce the impact of analyst subjectivity. The step-by-step design for corn and soybean labeling provided an additional benefit of allowing error sources to be isolated, thus, providing meaningful feedback for procedure modification.

Because of the apparent success of this procedure with corn and soybeans, conversion of the U.S. spring small grains procedure to a similar format was a logical step. This reformatting was accomplished in preparation for the U.S./Canada Wheat and Barley Exploratory Experiment.

2.1.3 THE OBJECTIVE REFORMATTED APPROACH TO LABELING (ref. 3)

An objective was established to develop a procedure for labeling spring small grains in the U.S. Northern Great Plains (USNGP) segments by converting the U.S. spring small grains and barley separation procedure, which was used during the TY project, to a format similar to the corn and soybeans decision logic (refs. 13 and 14). The techniques used in the TY project were to be enhanced whenever possible.

Following a comprehensive review of the TY project labeling procedures (ref. 12), scientists identified alternative methods for performing some of the steps. These methods leave fewer subjective decisions in the labeling process to the analyst. The new techniques were tested using segments from the develolpmental data set. Necessary modifications and revisions were made before incorporating them into the overall labeling procedure.

The objective labeling procedure is based primarily on analysis and observations of the segments comprising the developmental data set. Criteria used for selecting the segments were based upon (a) the segments having a sufficient number of acquisitions to adequately describe the growth cycle of spring small grains and (b) the segments having a reasonably large proportion of spring small grains, particularly barley.

Essentially three major divisions exist within the objective labeling procedure. These divisions are:

1. The separation of dots (pixels) into either cropland or noncropland
2. The separation of cropland dots into spring small grains or non-spring small grains. (In this document, non-spring small grains includes all crops other than spring small grains in addition to all nonagricultural areas such as forests, water, urban areas, and bare soil.)
3. The separation of spring-small-grain dots into barley or other spring small grains

For the cropland and noncropland separation, the procedure relies on a slightly modified portion of the decision logic for major land-use categories, a part of the corn and soybeans procedure (refs. 13 and 14.)

Because segments can be processed without an acquisition during the time when barley is green vegetation, the first major division had to be modified to ensure that barley would be labeled cropland. This modification allows fields to be labeled cropland (provided specific conditions are satisfied) even though acquisitions showing the crop growing are unavailable. Additionally, when responses are such that the decision is clearly noncropland, the dot is labeled as noncropland instead of attempting a further breakdown into range, forest, and other.

The successful identification of spring small grains is usually the result of an analyst's ability to recognize fields which follow the development pattern of spring small grains and isolate acquisitions on which most or all of the spring small grains exhibit similar characteristics (e.g., bare soil, green

vegetation, and harvested). If the coupling of two or more of these acquisitions provides a unique signature for spring small grains (e.g., bare soil on acquisition 1 and green vegetation on acquisition 2), accurate labeling should result. In order to develop procedures for this process, a window technique was devised to select acquisitions on which the appearance of spring small grains would be predictable. The desired characteristics of spring small grains on acquisitions selected to represent each window are presented in table 2-1.

If the correct acquisitions are selected, a description of the desired appearance of spring small grains, as a function of window, should allow accurate separation of spring small grains from non-spring small grains. In an attempt to provide a more objective description of appearance, green numbers and brightness (refs. 15, 16, and 17) were used in lieu of color descriptions for this procedure.

Observation of the behavior of the green number and brightness of spring small grains on segments from the developmental data set was used to establish the green number and brightness criteria for spring small grains as a function of acquisition and window. These criteria cutoffs were utilized in the decision logic for spring small grains.

For the separation of barley and other spring small grains, much of the TY project labeling procedure (ref. 12) was retained. However, there are several important modifications described in addendum 1, volume II, of this document and are summarized below:

a. The separation acquisition is selected using an objective procedure. This is the window 3 acquisiton.

b. The decision boundary on the green number versus brightness scatter plot is a straight line with fixed slope.

c. The concept of dot drift is introduced to assist in determining the location of the decision boundary. Dot drift is the direction of movement in the green number and brightness plane from the window 2 acquisition to the window 3 acquisition.

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TABLE 2-1.- DESIRED CHARACTERISTICS OF ACQUISITIONS AS A FUNCTION OF WINDOW

Window	Description of spring small grains	Product 1 appearance of spring small grains
1	Plowing/planting for spring small grains All spring small grains appear to be bare soil Spring wheat Robertson stage 0.8 to 2.6	Light to dark green, light to dark gray, and black
2	All spring small grains appear to be green vegetation. (Most of the summer crops appear to be bare soil.) Spring wheat Robertson stage 3.8 to 4.5	Red, pink, brown, and orange
3	Spring barley is turned/harvested; spring wheat, oats, and flax appear to be green vegetation. Spring wheat Robertson stage 4.7 to beginning of harvest.	Deep red, reddish brown, brown, orange, pink, yellow, gold, olive, white, gray, and green
4	All spring small grains appear to be turned/harvested.	Light to dark green, light to dark gray, white, yellow, gold, olive, and black

The definition of a minimum data set for processing segments with the reformatted labeling procedure reflects extensive LACIE experience in addition to observations of the segments from the developmental data set.

An acquisition in window 1 was known to be a requirement in mixed wheat areas to provide separation between winter and spring small grains. This requirement was extended to all of the areas of interest because of its additional value for separating natural vegetation and hay. (See tables 2-1 and 2-2.)

An acquisition in window 2 or window 3 is required to provide a date when spring small grains are growing. Since the barley separation technique relies on the observation of barley turning and harvested while the other spring small grains are in earlier stages, a window 3 acquisition is required to execute that portion of the procedure.

An acquisition in window 4 is essential in areas such as South Dakota and Minnesota to avoid confusion of summer crops such as corn with spring small grains.

A detailed description of the reformatted spring small grains labeling procedure used in Phase 2, Part 2, of the exploratory experiment is provided in reference 9. The general flow of the steps involved in the procedure is shown in figure 2-7 of this document. A detailed description of all the steps required for execution of the reformatted labeling procedure is documented in reference 9; a summary description follows.

When using the procedure, the analyst must first use crop calendars for spring wheat and barley to determine the opening and closing dates for each of the windows described in table 2-2 of this report. This is Step I in figure 2-7. Following acquisition selection (Step I), the combination of available acquisitions and windows is considered to determine the type of labeling, if any, that can be performed using the procedure. If the available acquisitions and windows are sufficient for barley separation, the entire procedure can be

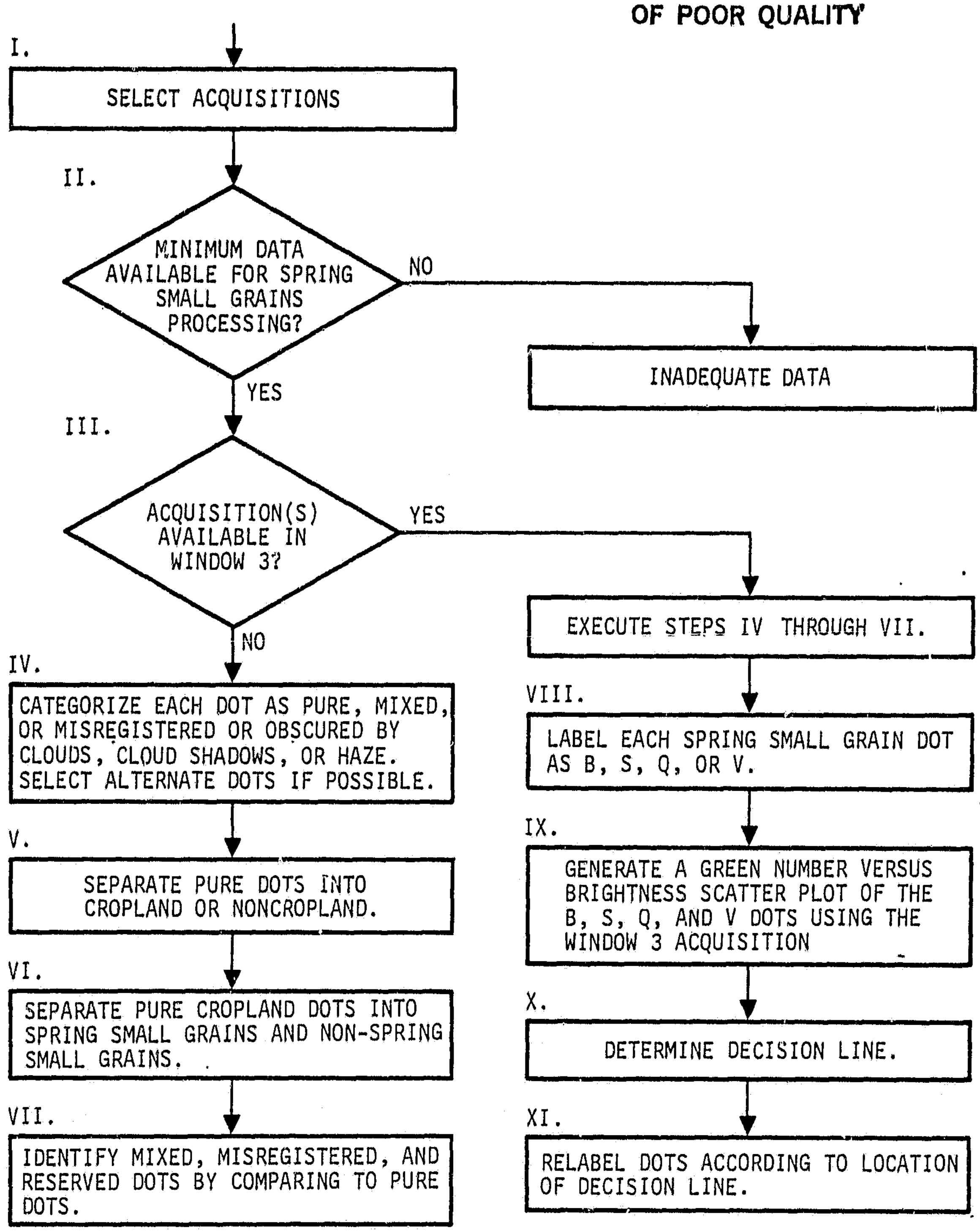

Figure 2-7.- The flow diagram of the reformatted spring small grains labeling procedure (ref. 9).

TABLE 2-2.- OBJECTIVE REFORMATTED LABELING PROCEDURE WINDOW DEFINITIONS USED IN CONJUNCTION WITH STATEWIDE HISTORICAL CROP CALENDARS[a]

Window	Open	Closed
1	Spring wheat, 50 percent planted minus 5 days	Spring wheat, 50 percent planted plus 18 days
2	Spring wheat, 50 percent headed minus 10 days	Spring wheat, 50 percent headed plus 10 days
3	Spring barley, 50 percent turning to ripe minus 6 days	Spring barley, 50 percent turning to ripe plus 6 days
4	Spring wheat, 50 percent harvested plus 15 days	Spring wheat, 50 percent harvested plus 30 days

[a]See figure 2-4.

executed. If no acquisition from window 3 is available, only the spring-small-grain portion (Steps IV through VII in fig. 2-7) of the procedure can be used.

2.2 MACHINE PROCESSING/CLASSIFICATION TEST - SUMMARY DESCRIPTION

2.2.1 GENERAL

The machine processing/classification test (ref. 3) consisted of processing and classifying the same 1979 United States spring wheat region segments used in the labeling procedures test. The objective of the test was to evaluate the accuracy and efficiency of alternative classification techniques.

A need for more efficient use of labeled samples in segment proportion estimation had previously been established by studies which showed that simple random sampling could produce results equivalent to maximum likelihood classification. During the Supporting Research project, a Bayes approach to proportion estimation using a stratified sample in response to this deficiency was developed (ref. 18). This technique was integrated with the labeling procedure to form a proportion estimation component. It was included in the exploratory experiment for evaluation.

The following alternative techniques for allocating samples and estimating crop proportion within each segment were evaluated (ref. 6).

a. Random sample/relative count - this technique allocates samples randomly and estimates crop proportions by determining the number of samples in a crop category and dividing by the total number of samples.

b. Proportional allocation/relative count - samples are allocated to clusters proportional to the cluster sizes, and the estimate is generated by determining the number of samples in a crop category per cluster and weighing the estimate by cluster size.

c. Proportional allocation/Bayesian estimator - the samples are allocated to clusters proportional to cluster size, and proportion estimation is calculated using the Bayesian estimator.

d. Bayesian sequential allocation/Bayesian estimator - samples are allocated to clusters sequentially in an attempt to minimize the mean square error (MSE), and a proportion estimate is calculated using the Bayesian estimator.

In the last three evaluations, the samples were stratified using the CLASSY clustering algorithm (refs. 19, 20, and 21).

2.2.2 BACKGROUND ON MACHINE PROCESSING

Since large-area acreage estimates for small grains depend upon segment-level proportion estimates, it is important that those proportion estimates be as accurate and precise as possible. Prior to the AgRISTARS program, several procedures were tested in an attempt to find an accurate and efficient method for estimating small-grain proportions. In the resultant method, Procedure 1 (P1), labels were used in the random selection of training pixels to start a clustering algorithm. Then, cluster statistics were used to produce a maximum likelihood classification of the scene into 2- or 3-class strata. Finally, stratified proportion estimates were made using a second random set of labeled dots. However, this classification component provided no better results than those which could have been produced through simple random sampling. Thus, clustering had not been an effective method.

Consequently, a new clustering algorithm was developed (refs. 21 and 22). The new algorithm used clusters to generate strata within which the crop proportions could be estimated. One advantage of this algorithm was that, as an unsupervised routine, a first set of training dots was not needed (as in P1).

In addition, a proportion estimation technique (ref. 18) which used the clusters of this algorithm was developed. This technique involved Bayesian estimation of cluster-level proportions based on historical information concerning cluster purities. The cluster-level estimates were then weighted by their relative cluster sizes and aggregated to produce the segment-level estimate. Use of this technique was expected to provide better proportion estimates. The technique also implemented sequential sampling in an attempt to sample the

segment clusters more effectively and further reduce the expected of the proportion estimation. Characteristic of this new estimation technique was the selection of dots, one at a time. It is known as the Bayesian sequential allocation/Bayesian estimator. The sampling technique was an attempt to minimize the MSE of the proportion estimate. Before each sampling of a dot, expected effects to MSE estimates were made for each cluster; and, on the basis of these estimates, a sample was taken from the cluster that was expected to most reduce the MSE. This manner of sampling provided an additional feature: the option of sampling with a fixed sample size or varying the sample size from segment to segment. Varying the sample size could be managed by halting the sampling when a predetermined threshold was obtained for the internal MSE estimate. Varying the sample sizes in this manner was to provide uniform accuracy across segments by sampling more frequently from more "difficult" segments.

A 10-segment development test of the Bayesian sequential allocation/Bayesian estimator (ref. 23) showed that there was at least a 2 to 1 reduction in the MSE from that observed from P1, a reduction in proportion estimation error, and improved analyst labeling accuracy. Table 2-3 summarizes the proposed advantages of the Bayesian sequential allocation/Bayesian estimator technique compared to the earlier P1 proportion estimation technique.

2.3 CROP DEVELOPMENT STAGE MODEL TEST - SUMMARY DESCRIPTION

2.3.1 GENERAL

The crop development stage model test consisted of estimating the planting date and phenological development stages of wheat and barley in 49 segments within the U.S. spring wheat region. Figure 2-8 shows the location of the segments used in the test.

The objectives of this test were:

a. To evaluate alternative models.

DATA SET

- FORTY-NINE SEGMENTS IN THE SPRING WHEAT AREAS OF THE U.S. GREAT PLAINS.
- 1979 PERIODIC OBSERVATIONS COLLECTED BY ENUMERATORS AT 9- TO 18-DAY INTERVALS CORRESPONDING TO LANDSAT OVERPASS DATES.

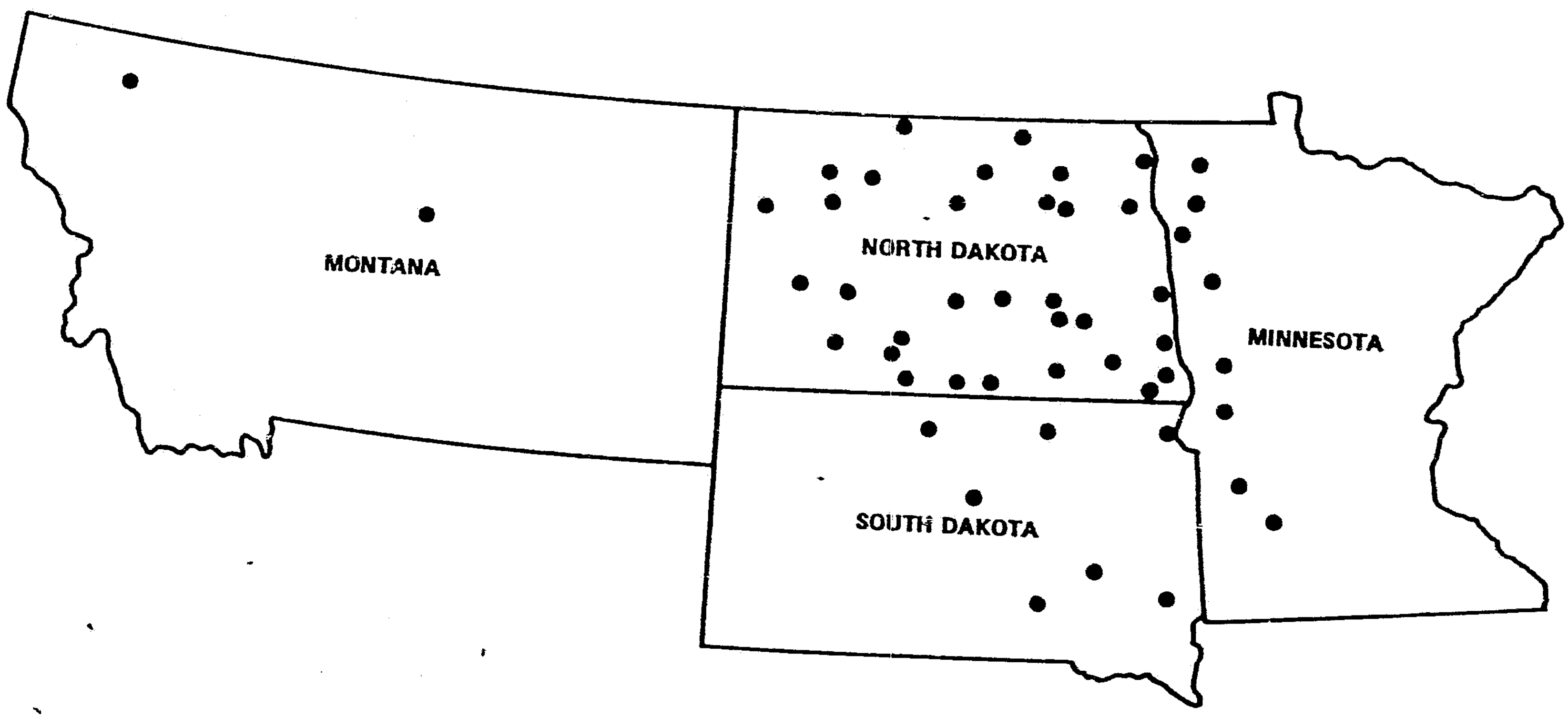

Figure 2-8.- Segments used in the crop development stage model test.

TABLE 2-3.- PROCEDURE 1 COMPARED TO THE BAYESIAN SEQUENTIAL ALLOCATION/BAYESIAN ESTIMATOR TECHNIQUE

Step	Procedure	Bayesian sequential allocation/ Bayesian estimator	Proposed advantage
1. Stratification	ISOCLS Use type 1 labeled dots to collapse clusters into two strata	CLASSY	No need to label dots to create a small number of strata for sampling, thus more efficient
2. Allocation of dots to be labeled	Approximately proportional to size of strata (poststratification)	Sequential to minimize MSE	Requires less dots for same accuracy by incorporation of: 1. Prior information of distribution of cluster purity 2. Knowledge of previously labeled samples More accurate labeling for selected dots
3. Stratum-level estimation	Relative count	Bayes	Reduction in MSE for equivalent number of dots by including prior information of distribution of cluster purity
4. Segment-level estimation	Weighted average over strata	Weighted average over strata	None (same)

b. To determine which combination of planting date and phenological development stage models most accurately estimate the development of wheat and barley.

c. To determine if the various models are sufficiently accurate to be incorporated into objective labeling procedures.

The models evaluated in this test are:

a. Planting date models tested:

   - Normal planting date model (ref. 24)
   - Feyerherm planting date model (ref. 25)

b. Wheat phenological development stage models tested:

   - Original Robertson wheat model (ref. 24)
   - Improved Robertson wheat model, version 1 (ref. 25)
   - Improved Robertson wheat model, version 2 (ref. 25)

c. Barley phenological development stage model tested:

   - Williams barley model (ref. 26)

The Feyerherm and the normal planting date models were evaluated on their ability to accurately predict the median planting dates in the segments. The basis for comparison was the ground-truth median planting dates. The ground-truth median planting dates for spring wheat and barley were obtained by calculating the date at which 50 percent of the spring wheat and barley fields in each of the segments were observed and planted. Discrepancies between ground truth and the models were measured in number of days.

The performances of the three Robertson growth stage models were evaluated using the ground-truth median growth stages as the basis for comparison. Observed median planting dates were used to initiate the models. The ground-truth median growth stages for spring wheat and barley were obtained by calculating the observed median stage for spring wheat and barley fields within each of the segments for each of the dates on which the stages were observed. The comparison of the model's prediction versus the observed crop stage yielded errors in terms of crop stages associated with each of the models.

The barley growth stage model was evaluated using the observed median planting dates for barley to initiate the models and, subsequently, comparing the model prediction of stage with the ground-truth median growth stages for barley.

2.3.2 DESCRIPTION OF THE GROWTH STAGE MODELS

Robertson's concept (ref. 27) is based on certain physiological processes that are central to the development of spring wheat. Since temperature and photoperiod are two primary environmental factors that influence the phenological development, a photothermal concept was used to compute the development of a crop over five fairly short and uniform physiological periods. The triquadratic responses of temperature and photoperiod were estimated for each of the phenological stages by an interative regression technique.

The improved Robertson model, verisons 1 and 2, are improvements over the original Robertson model with respect to the photoperiod and temperature responses. The photoperiod response is limited to stages between emergence and flowering. The thermal response for subsequent stages are adjusted to represent realistic physiological responses. The development rates of spring wheat immediately before and after flowering are responsive primarily to the daily maximum temperature.

The Williams barley model is based approximately on the same concept as the Robertson model; the difference is that the coefficients were developed specifically for barley.

Figure 2-9 is a schematic of the model's input requirements and resultant output data. The normal model, although not an agrometeorological model, is included in figure 2-9 for the sake of completeness. It is based on historical data averaged for the crop reporting district. The daily minimum and maximum temperatures are obtained from reports of weather stations nearest the segments.

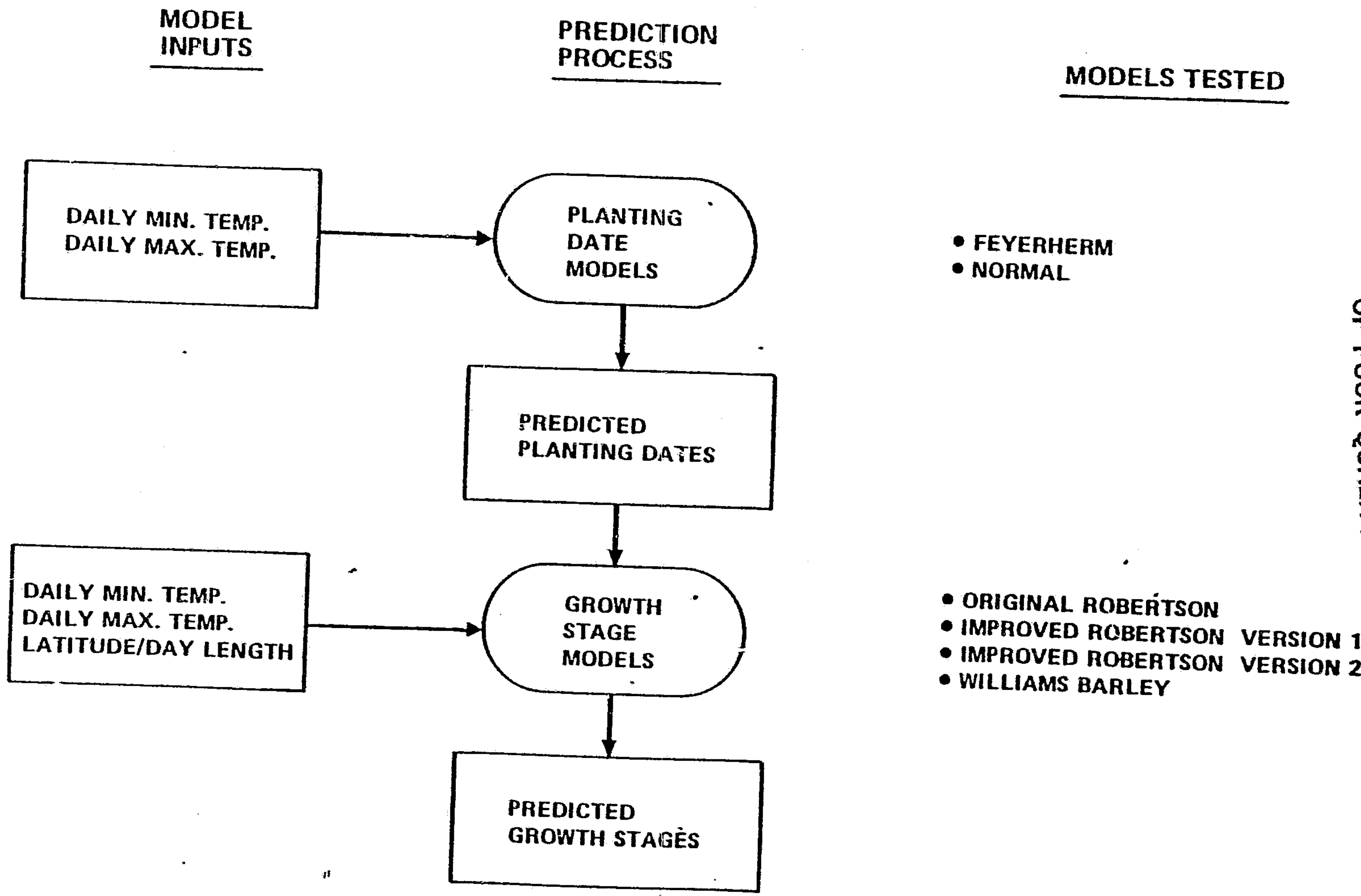

Figure 2-9.- Schematic of the planting date and growth stage model evaluation process.

3. EXPERIMENT RESULTS

3.1 LABELING PROCEDURES TEST RESULTS - SUMMARY

The shakedown test (Phase 1) of the new objective labeling procedure using 1978 Landsat data indicated:

a. Excellent spring small grains labeling accuracy results. The overall accuracy was 76 percent.

b. Labeling results were comparable to those obtained from an analyst intensive procedure performed on 1978 data (76 percent versus 75 percent).

c. Consistency between the analysts was very good. Overall, the agreement on labels was 85 percent.

The expanded labeling test (Phase 2) using the 1979 data provided the following results:

a. Labeling accuracy results for spring small grains were similar to the integrated analysis procedure, although slightly lower, 66 percent for the objective labeling procedure versus 76 percent for the integrated analysis procedure.

b. The 1979 error characterization study identified the areas requiring improvements to the objective labeling procedure (SSG-1).

   (1) The procedure processed only 25 percent of the available segments.

   (2) Confusion of pasture with small grains was a problem.

   (3) Crop calendar improvements were required in order to better select acquisitions for processing.

The wheat/barley separation procedure results are:

a. Segments with 10 percent and above in barley were not available for testing.

b. Segments were not available which have both winter wheat and spring barley, as in the foreign similar environment.

c. The labeling accuracy was approximately 50 percent in low-density barley segments (those containing 5 percent or less).

Consistency of labeling between two analysts labelings using the reformatted labeling procedure (SSG-1) averaged 78 percent (Phase 2).

The summary given in section 3.1 is based on information in reference 3.

3.1.1 SHAKEDOWN TEST, PHASE 1, WITH 1978 DATA - DETAILED RESULTS

3.1.1.1 Experiment Design for the Shakedown Test, Phase 1, 1978 Data

In the shakedown test, all 209 dots for six segments were labeled using data from the 1978 crop year. The actual number of dots evaluated per segment varied downward from 209 because of clouds, cloud shadows, data dropouts, striping, or missing ground-truth inventory. The loss was a small percentage of the dots. Locations of the segments are shown in figure 2-2, section 2. Each of the segments was labeled by two analysts working independently. By comparing the two sets of labeling results, the consistency of the objective procedure could be evaluated. Five of these six segments were previously processed using the integrated labeling procedure. (Refer to addendum 1, volume II, of this document for details.) These labeling results were used to compare the accuracy of the objective reformatted labeling procedure with the accuracy of the integrated labeling procedure.

3.1.1.2 Shakedown Test, Phase 1, Overall Labeling Accuracy for Final Labels

Table 3-1 shows the labeling accuracy for each of the categories labeled non-small grains, barley, and other small grains. The labeling accuracy is shown for all the dots labeled and for those dots which were determined by the analyst to be pure, mixed, or misregistered. The labeling accuracy was greater for the pure dots (which were labeled using the decision logic) than for the impure dots (which were labeled by comparison with the pure dot labels). The numbers in parentheses in the table show the percentage of dots correctly labeled when both analysts agreed on the label. The labeling accuracies were, in general, greater when there was agreement between the analysts.

TABLE 3-1.- ANALYST LABELING ACCURACY - OBJECTIVE REFORMATTED LABELING PROCEDURE, SHAKEDOWN TEST, PHASE I

Note: The numbers in parentheses show the percentage of dots correctly labeled when both analysts agreed on the label.

Crop category	Correctly labeled dots, %			
	All dots	Pure dots	Mixed dots	Misregistered dots
Nonsmall grains	91 (95)	94 (97)	73 (78)	82 (91)
Small grains (except barley)	72 (82)	74 (84)	66 (83)	55 (63)
Barley	51 (49)	50 (51)	60 (-)	50 (-)
Total small grains	77 (86)	79 (87)	73 (86)	67 (76)

Table 3-2 shows a comparison, on a segment-by-segment basis, between accuracy obtained using the objective reformatted labeling procedure and that obtained using the integrated labeling procedure. Overall, the reformatted labeling procedure produced labeling accuracies which were comparable to the accuracies for the integrated labeling procedure. For some segments, the reformatted labeling procedure obtained better results in certain categories than did the integrated labeling procedure, whereas, on other segments the reverse was true.

The barley labeling accuracy was not very high for either procedure, with only half of the barley being labeled correctly. However, the segments involved in this test had an average barley proportion of only 5 percent, with two segments containing no barley at all. Because of the nature of the barley/other-small-grains labeling technique, the labeling accuracy for barley cannot be adequately tested if a reasonable amount of barley is not present. Therefore, in all of the subsequent discussions, barley is considered part of the small-grains category, and labeling accuracies are evaluated for small-grains/nonsmall-grains labeling only.

The labeling accuracies for individual crops are shown in table 3-3. None of the nonsmall grain crops were consistently mislabeled; of the small-grain crops, only flax was incorrectly labeled more often that it was correctly labeled.

Note: This type of error for flax was observed during Phase III of LACIE (ref. 28) and the Transition Year (ref. 29). Although flax is not a small grain, its spectral signature is similar and is considered as grouped with small grains. Because there is so little flax, it is difficult to decide (on the basis of these and prior results) whether flax should be identified as a small grain or nonsmall grains.

TABLE 3-2.- SEGMENT-LEVEL RESULTS OF THE SHAKEDOWN TEST FOR THE OBJECTIVE REFORMATTED AND INTEGRATED PROCEDURES

Segment number[a]	Procedure	Correctly labeled dots, %			Segment characteristics
		Small grains	Barley	Nonsmall grains	
1542	Reformatted	91	-	93	25% small grains (no barley)
	Integrated	42	-	96	3% other crops
1584	Reformatted	86	44	88	50% small grains 11% barley
	Integrated	93.4	45	94	Acquisitions deficient for barley
1656	Reformatted	57	-	95	75% noncropland 7% small grains
	Integrated	52.6	-	97	No barley
1664	Reformatted	70	81	95	38% small grains 8% barley
	Integrated	87	54.5	94	27% other crops
1811	Reformatted	56	36	81	25% small grains 2% barley
	Integrated	70	0	94	40% other crops
Overall	Reformatted	76	52	91	
	Integrated	75	55	95	

[a]Segment 1514 was not processed during the Transition Year.

TABLE 3-3.- ANALYST LABELING ACCURACY FOR INDIVIDUAL CROPS - OBJECTIVE REFORMATTED LABELING PROCEDURE, SHAKEDOWN TEST, PHASE 1 RESULTS

Crop	Number of dots labeled	Crops correctly labeled, %
Nonsmall grains		
Alfalfa	58	81
Corn	155	78
Sunflower	109	92
Sugar beets	14	79
Grass	112	93
Hay	137	91
Pasture	539	95
Trees	12	83
Water	34	94
Nonagricultural	111	96
Homestead	23	87
Idle	257	89
Small grains		
Spring barley	111	83
Spring wheat	443	81
Flax	34	41
Spring oats	92	62
Duram wheat	16	100

3.1.1.3 Reformatted Procedure Cropland/Noncropland Labeling Accuracy, Shakedown Test, Phase 1

The dots considered in evaluating the corpland/noncropland labeling accuracy were those which had been determined pure by the analyst. Figure 3-1 is an illustration of the cropland/noncropland decision logic. The labeling accuracy for the cropland/noncropland decision logic is given in table 3-4(A). The labeling accuracy obtained as a function of the path taken through the decision logic is shown in table 3-4(B). None of the paths through the decision logic consistently produced wrong answers.

When the decision logic method was used, 66 percent of the area within the segments was cropland. Labeling accuracy for the dots labeled cropland by decision 3 in the decision logic was lower than the accuracy for dots labeled noncropland, resulting in no problem as the incorrectly labeled cropland dots remained in the flow of the decision logic; they could be labeled nonsmall grains later. Therefore, if either cropland or noncropland were to have a low labeling accuracy, it is best for the dots labeled cropland to be mislabeled as they remain in the decision logic. No major problems surfaced when using the cropland/noncropland logic.

3.1.1.4 Reformatted Procedure Small Grains/Nonsmall Grains Labeling Accuracy, Shakedown Test, Phase 1

Table 3-5(A) shows the labeling accuracy for the small-grains/nonsmall-grains decision logic. The dots used in evaluating the small grains/nonsmall-grains labeling accuracy are those which were correctly identified as cropland by the analyst. The accuracy for this logic appears to be quite good, especially when there is agreement between the analysts on the label. In table 3-5(B), a wide variety of paths through the logic are used. None of the paths appear to produce consistently incorrect answers, which indicates that there are no major problems with the logic.

As stated previously, there was not enough barley in these segments to determine if the barley separation procedure was working properly; the accuracy in separating barley from other small grains is presented in table 3-6. The dots

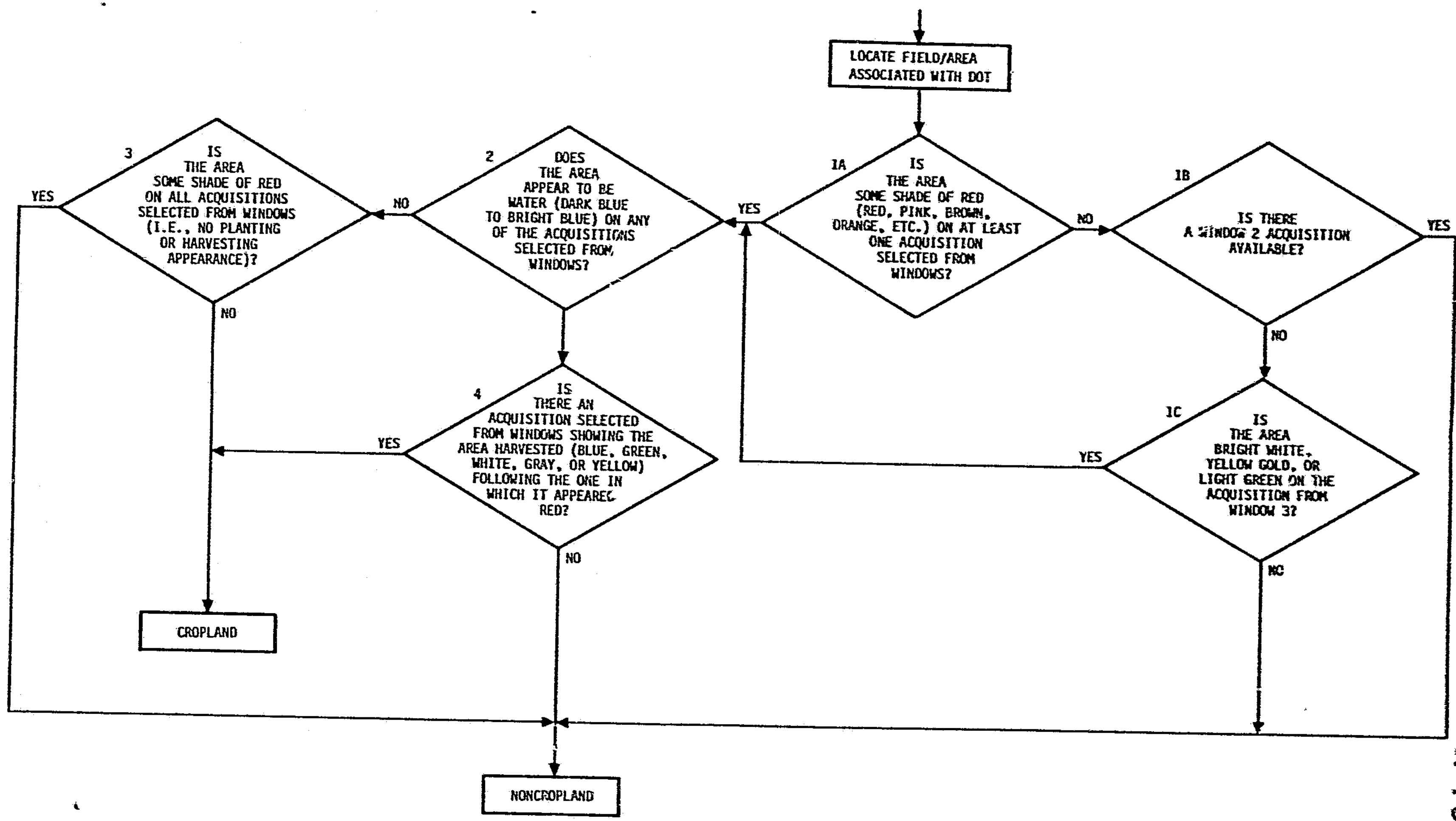

Figure 3-1.- Decision logic for cropland/noncropland, questions 1A, 1B, 1C, 2, 3, and 4 (ref. 9).

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TABLE 3-4.- LABELING ACCURACY FOR CROPLAND/NONCROPLAND - OBJECTIVE REFORMATTED LABELING PROCEDURE, SHAKEDOWN TEST, PHASE 1 RESULTS

(A) OVERALL LABELING ACCURACY

Crop type	Correctly labeled dots, %
Cropland	84 (90)
Noncropland	74 (82)

(B) ACCURACY BY PATH THROUGH THE DECISION LOGIC

[The numbers in parentheses reflect the percentage of labeled dots when both analysts agreed on the label.]

Responses to cropland/noncropland decision logic questions (See fig. 3-1) 1A	1B	1C	2	3	4	Labeling decision	Total dots labeled, %	Correctly labeled dots, %	Crops which most frequently produce errors
Y	-	-	N	N	-	Crop	52	77 (85)	Grass, pasture, nonagricultural, idle
Y	-	-	N	Y	-	Noncrop	32	82 (86)	Alfalfa, corn, spring wheat, barley
N	Y	-	-	-	-	Noncrop	9	84 (95)	Spring wheat, barley
N	N	Y	N	N	-	Crop	3	90 (92)	Idle
N	N	N	-	-	-	Noncrop	2	85 (-)	Spring wheat

Symbol definition:

N = no
Y = yes

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TABLE 3-5.- LABELING ACCURACY FOR SMALL GRAINS/NONSMALL GRAINS DECISION LOGIC - OBJECTIVE REFORMATTED LABELING PROCEDURE, SHAKEDOWN TEST, PHASE 1 RESULTS

(A) OVERALL LABELING ACCURACY

Crop type	Correctly labeled dots, %
Small grains	88 (94)
Nonsmall grains	89 (92)

(B) ACCURACY BY PATH THROUGH THE DECISION LOGIC

[The numbers in parentheses reflect the percentage of labeled dots when both analysts agreed on the label.]

Responses to small grains/ nonsmall grains decision logic questions (See fig. 3-1) 1A	1B	1C	2	3	4	Labeling decision	Total dots labeled, %	Correctly labeled dots, %	Crops which most frequently produce errors
Y	-	-	Y	-	Y	SG	22	94 (96)	Corn, sunflower
Y	Y	-	-	N	-	NSG	15	73 (78)	Spring wheat
Y	Y	-	-	-	Y	SG	13	97 (98)	Hay
Y	-	-	Y	Y	Y	SG	10	94 (95)	Sunflower
Y	Y	-	-	-	N	NSG	7	84 (100)	Spring wheat
Y	Y	-	-	Y	Y	SG	6	88 (90)	Corn
Y	-	-	Y	-	N	NSG	6	92 (95)	Spring wheat
Y	Y	-	-	Y	-	SG	6	95 (100)	-
N	-	-	-	-	-	NSG	5	81 (87)	Spring oats
Y	N	N	-	-	-	NSG	3	95 (100)	-

Symbol definition:

NSG = nonsmall grains
SG = small grains
Y = yes
N = no

TABLE 3-6.- LABELING ACCURACY FOR SMALL GRAINS/BARLEY DISCRIMINATION - OBJECTIVE REFORMATTED PROCEDURE, SHAKEDOWN TEST, PHASE 1 RESULTS

Crop type	Correctly labeled dots, %
Small grains (except barley)	95 (98)
Barley	61 (54)

used to determine this accuracy are those which were correctly labeled as small grains by the analyst. Only about half of the barley is correctly labeled, whereas almost all of the other small grains are labeled correctly.

3.1.2 THE EXPANDED LABELING TEST (PHASE 2, PARTS 1 AND 2) USING 1979 DATA - DETAILED RESULTS

The expanded labeling test conducted during Phase 2 using the 1979 data set consisted of Parts 1 and 2. Part 1 was an analysis using the earlier, more subjective, integrated procedure SSG-0. The technology is the same which was used during LACIE and the TY projects. This methodology utilizes an analyst's experience and intuition for advantage in achieving best results. Part 2 was a test using the objective reformatted labeling procedure SSG-1 and applying it to nine segments in the USNGP, crop year 1979. Procedure SSG-1 utilizes specified decision logic for labeling. The results from the integrated test (Phase 2, Part 1) were used for comparison with results from the objective reformatted labeling procedure test (Phase 2, Part 2). A comparison of the final results and ground truth for the objective reformatted and the integrated procedures is given in table 3-7. The following observations/conclusions were noted when comparing the results of the respective procedures.

a. The rate of segment processibility is higher using the integrated procedure. (Thirty-five segments were processed with equivalent accuracies to the nine segments of the reformatted procedure. The integrated procedure can be executed without being limited by predefined acquisition requirements.)

TABLE 3-7.- EXPANDED LABELING TEST RESULTS - PHASE 2, PARTS 1 AND 2

[The numbers in parentheses reflect the labeling accuracy when both analysts agreed on the label.]

Crop category	Analyst labeling accuracy, % correctly labeled			
	Phase 2, Part 1 Integrated procedure (SSG-0)		Phase 2, Part 2 Reformatted procedure (SSG-1), 9 segments	
	Same 9 segments as used in SSG-1	All segments available, 35 segments	All dots	Pure dots
Nonsmall grains	94	94	75 (81)	76 (81)
Total small grains	76	73	66 (77)	65 (76)
Small grains except barley	69	66	61 (73)	61 (73)
Barley	59	41	15 (20)	16 (21)

b. Although slightly lower, the labeling accuracies of the new reformatted procedure (SSG-1) compares favorably to accuracies of the integrated procedure (SSG-0) for small grains, with and without barley.

c. The labeling accuracies of the reformatted procedure for nonsmall grains were low compared to results from the integrated procedure.

d. Labeling accuracies for barley only are unacceptable with either procedure.

e. The results for the objective reformatted procedure did not change when only pure dots were evaluated.

The data reported in section 3.1.2 were extracted from working papers of E. R. Magness, Lockheed Engineering and Management Services Company, Inc., 1980.

3.1.2.1 Labeling Accuracy of the New Objective Reformatted Labeling Procedure, Phase 2, Part 2

Labeling accuracies were determined for two analysts and for each segment. Random dot proportion estimates were then tabulated for the best analysis of each segment. The evaluation was based on comparing analyst labels to the derived ground truth. The labeling accuracy for all dots labeled was 71.6 percent for spring small grains and 82.5 percent for nonsmall spring grains. These data are illustrated in figure 3-2.

The labeling accuracy of spring small grains compares well with accuracies obtained in the past using purely interpretive methods (e.g., the integrated procedure). However, the labeling accuracy for nonsmall spring grains is much lower than accuracies obtained in the past. When viewed from the standpoint of proportion estimation for the nine segments, this low accuracy results in a relative overestimation of spring small grains by 23 percent.

The clerical and implementation errors, errors related to procedural shortcomings, and confusion errors between barley and other spring small grains are characterized in the following paragraphs.

OVERALL ACCURACY: Best of two analyses (accumulated)

Ground Truth

$$
\begin{array}{ll}
 & \begin{array}{cc} \quad\quad S \quad\quad & \quad\quad N \quad\quad \end{array} \\
\text{Analyst} \begin{array}{c} S \\ N \end{array} & \left[\begin{array}{cc} \frac{305}{426} = 0.716 & \frac{209}{1191} = 0.175 \\ \frac{121}{426} = 0.284 & \frac{982}{1191} = 0.825 \end{array}\right]
\end{array}
$$

Legend:

N = Nonsmall spring grains
S = Spring small grains

Ground Truth

$$
\begin{array}{ll}
 & \begin{array}{ccc} \quad\quad S \quad\quad & \quad\quad B \quad\quad & \quad\quad N \quad\quad \end{array} \\
\text{Analyst} \begin{array}{c} S \\ B \\ N \end{array} & \left[\begin{array}{ccc} \frac{269}{397} = 0.678 & \frac{17}{29} = 0.586 & \frac{162}{1191} = 0.136 \\ \frac{15}{39.7} = 0.378 & \frac{4}{29} = 0.138 & \frac{47}{1191} = 0.839 \\ \frac{113}{397} = 0.284 & \frac{8}{29} = 0.276 & \frac{982}{1191} = 0.825 \end{array}\right]
\end{array}
$$

Legend:

B = Barley
N = Nonsmall spring grains
S = Spring small grains

Figure 3-2.- Accuracies of the objective reformatted labeling procedure, Phase 2, Part 2 (nine segments of the 1979 crop year segments).

3.1.2.2 Spring Small Grains Error Characterization, Phase 2, Parts 1 and 2

Labeling error characterization for the objective reformatted labeling procedure and the integrated procedure are summarized in tables 3-8 and 3-9.

The confusing of pasture with spring small grains and mixed or misregistered pixels contributed 30 percent and 25 percent, respectively, to the labeling errors when using the reformatted procedure (table 3-8). Similarly, 25 percent of the labeling errors for the integrated procedure were due to border/edge pixels. Another 25 percent of the total error with the integrated procedure was attributed to the omission of late developing spring small grains (table 3-9).

3.1.2.3 Characterization of Errors Common to Both Processings, Phase 2, Part 2

For the nine segments, an average of 53 dots per segment were mislabeled by both analyst processings. This ranged from 8.2 percent to 19.1 percent of the dots in the nine-segment data set. (The actual number of dots in error ranged from 26 in segment 1676 to 64 in segment 1457.)

3.1.2.3.1 Characterization of Errors Related to Implementation, Both Processings, Phase 2, Part 2

A characterization of labeling errors which were related to the implementation of the reformatted procedure and common to both of the analysts was conducted. The results indicated an average of 14.3 dots per segment (3.9 percent) were incorrectly labeled because of segment procedure clarity or implementation probelms. These causes are listed below:

a. Acquisition selection, 3.8 dots per segment - errors of omission

b. Cropland/noncropland separation question implementation, 8.2 dots per segment - errors of commission.

c. Clerical, 2.3 dots per segment - omission and commission errors.

Labeling errors found to be caused by improper utilization of the acquisition selection procedure resulted in errors of omission. This occurred in two

TABLE 3-8.- THE OBJECTIVE REFORMATTED PROCEDURE LABELING ERROR CHARACTERIZATION (9 SEGMENTS) - PHASE 2, PART 2

Error causes, all dots	Relative Importance, %
Pasture: Commission to spring small grains	30
Mixed: Misregistered, omission and commission	25
Summer crop: Commission to spring small grains (sunflowers)	10
Crop calendar: Omission of spring small grains	10
Idle/fallow: Commssion to spring small grains	5-10
Procedure variability and clerical	15-20

TABLE 3-9.- THE INTEGRATED PROCEDURE LABELING ERROR CHARACTERIZATION - PHASE 2, PART 1

Error causes	Relative importance, %
Border/edge: Omission and commission	25
Late development of spring small grains: Omission	25
Nonsmall spring grains follow small spring grains temporal trajectory: Commission	15
Signature confusion on a single date: Omission	10
Spring small grains follow nonsmall spring grains temporal trajectory: Omission	10
Early development of spring small grains: Omission	5
Miscellaneous	10

segments: the incorrect selection of the window 1 acquisition (too late) for segment 1394 and the use of an incorrect time period "A" acquisition for segment 1387.

The analysts encountered difficulty in implementing the questions in the crop land/noncropland decision logic (figure 3-1). If the analysts had applied the questions more objectively, the errors probably would not have occurred. Most of the difficulty with the cropland questions occurred in segments located in North Dakota, agrophysical unit (APU) 21, where pasture was committed to spring small grains.

3.1.2.3.2 Characterization of Errors Related to the Procedure, Both Processings, Phase 2, Part 2

The tree diagram and data, given in figures 3-3, 3-4, and 3-5, provide a breakdown of the procedure related to errors according to their cause.

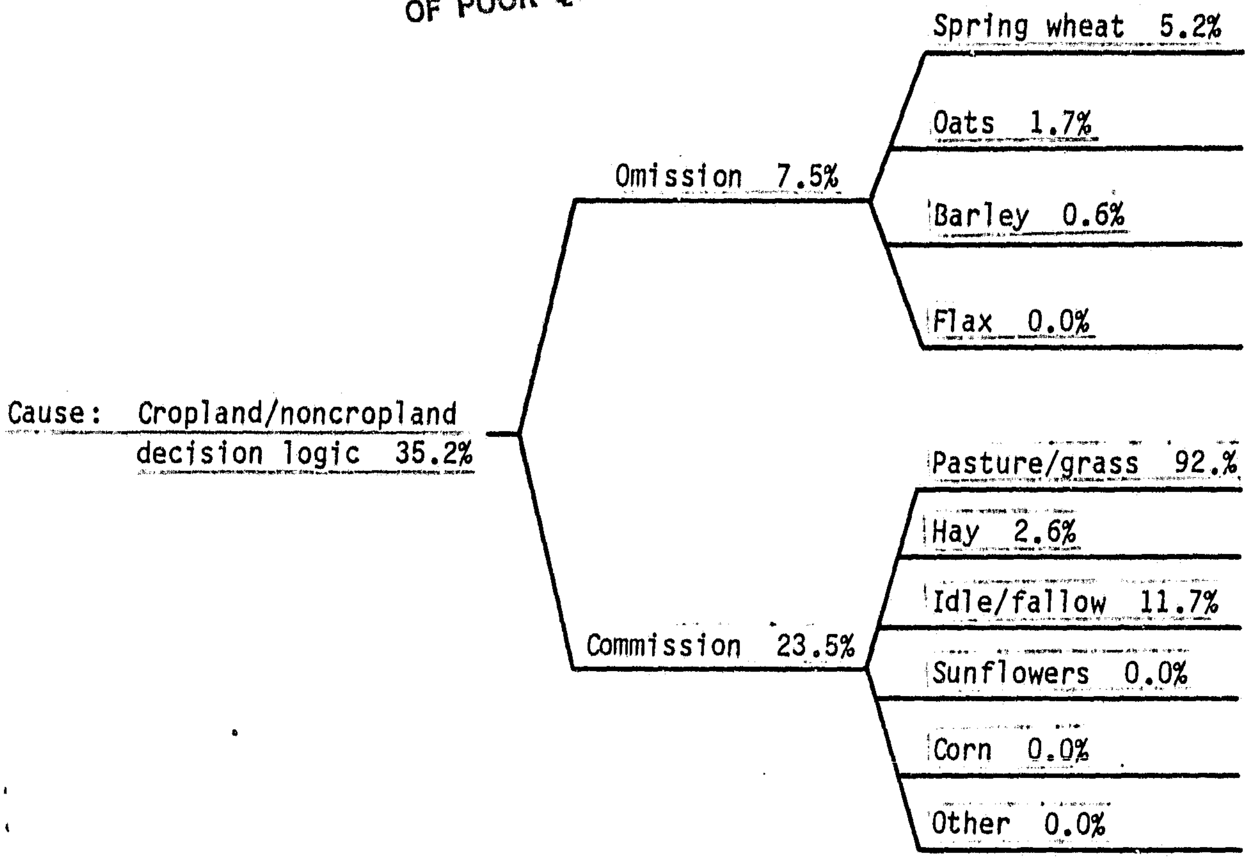
3.1.2.4 Characterization of Errors Made in a Single Processing, Phase 2, Part 2

For the nine segments, an average of 44.4 dots per segment were labeled incorrectly by one of the two analysts, but not by both analysts. The number of errors that were not in common with the processings of the two-analysts processings ranged from a low of 25 in segment 1627 to a high of 69 in segment 1571. These errors represented an error rate, ranging from 7.3 percent to 17.5 percent for the segments.

3.1.2.4.1 Characterization of Errors Related to Implementation, Single Processing, Phase 2, Part 2

A characterization of labeling errors which were related to the implementation of the reformatted procedure and not in common to both analysts was conducted. The results indicated an average of 14.9 dots per segment in this category (3.7 percent) were incorrectly labeled because of segment procedure clarity or implementation problems. These causes are listed below.

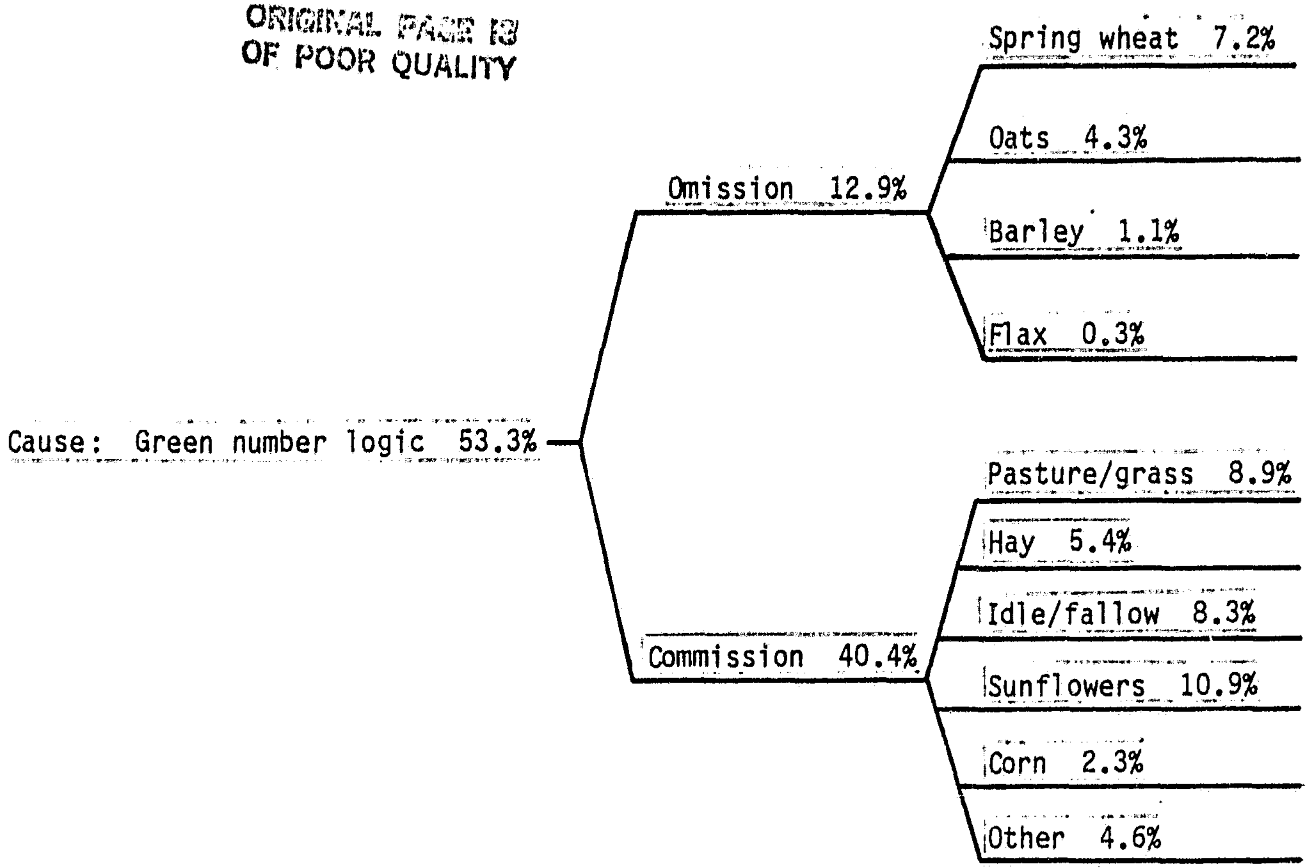
a. Acquisition selection, 0.8 dots per segment - errors of omission



The percentage of the errors made when answering each question in the cropland/noncropland decision logic shown in figure 3-1 is given below.

Crop	Question number and percentage of error					
	1A	1B	1C	2	3	4
Spring wheat	0.6		0.6		4.0	
Oats	0.3				1.4	
Barley					0.6	
Pasture/grass	2.3		1.7		5.2	
Hay					2.6	
Idle/fallow			9.7		2.0	
Total	3.2		12.0		15.8	

Figure 3-3.-Cropland/noncropland decision logic error characterization, both processings, Phase 2, Part 2.



The percentage of dots incorrectly identified by the logic for each window/period is given below:

Crop	Window/period and percentage of dots incorrectly identified					
	1	2	3	A	4	ALL
Spring wheat	2.6	0.9		2.0	1.7	
Oats	2.0				2.3	
Barley	1.1					
Flax	0.4					
Pasture/grass						8.9
Hay						5.4
Idle/fallow						8.3
Sunflowers						10.9
Other						4.6
Total	6.1	0.9		2.0	4.0	38.1

Figure 3-4.- Green number decision logic error characterization, both processings, Phase 2, Part 2.

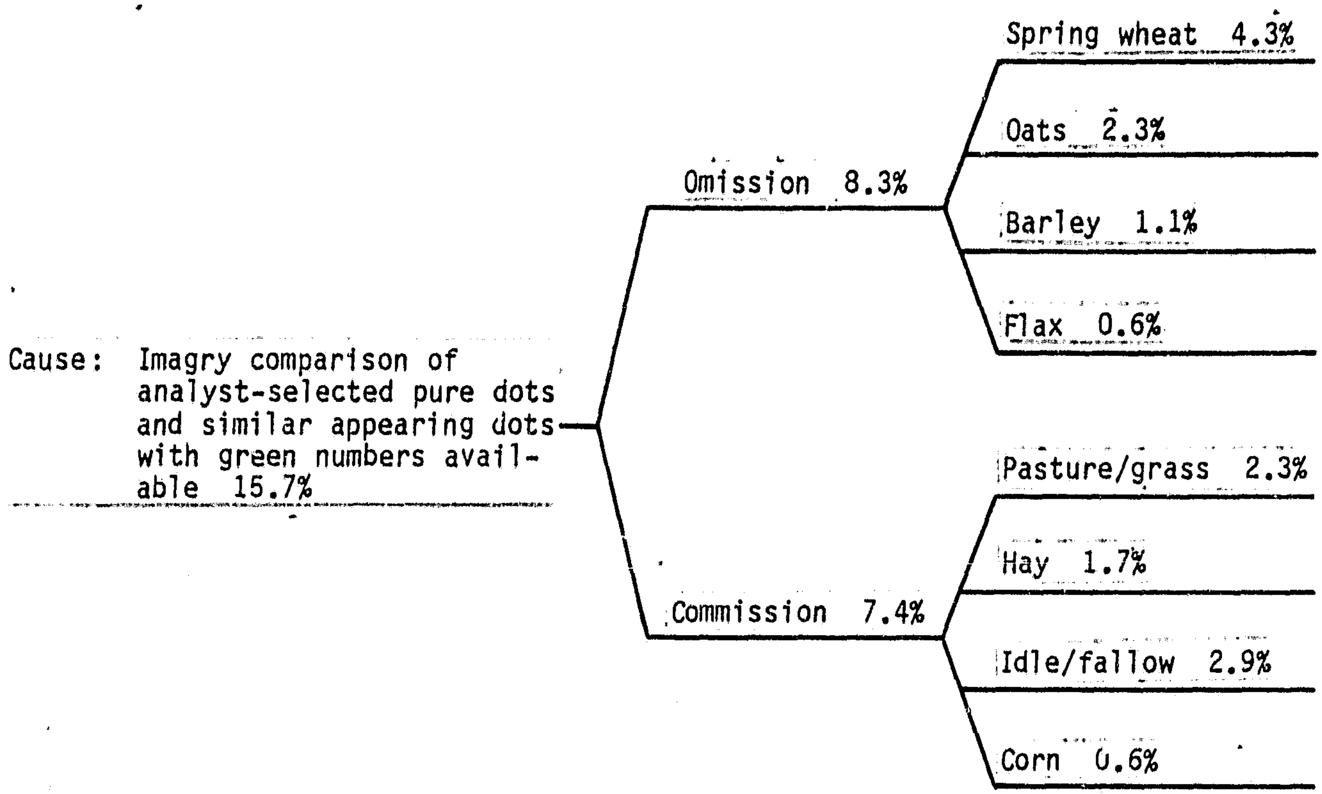


Figure 3-5.- Imagery comparison error characterization, both processings, Phase 2, Part 2.

b. Cropland/noncropland separation question implementation, 7.4 dots per segment

c. Clerical, 6.7 dots per segment

Four out of seven acquisition selection errors were made in segment 1394; two errors were in segment 1457. All of the acquisition selection-related errors were errors of omission. Implementation difficulty with the cropland/noncropland separation questions occurred primarily in segment 1387, APU 19, of North Dakota (35 errors) and segment 1485, APU 17, of South Dakota (20 errors). The clerical errors were made primarily in segment 1457 (32 errors) and segment 1394 (17 errors).

3.1.2.4.2 Characterization of Errors Related to the Procedure, Single Processing, Phase 2, Part 2

The remaining valid procedure-related errors are given in figures 3-6, 3-7, and 3-8 according to the point in the procedure logic at which the errors occurred.

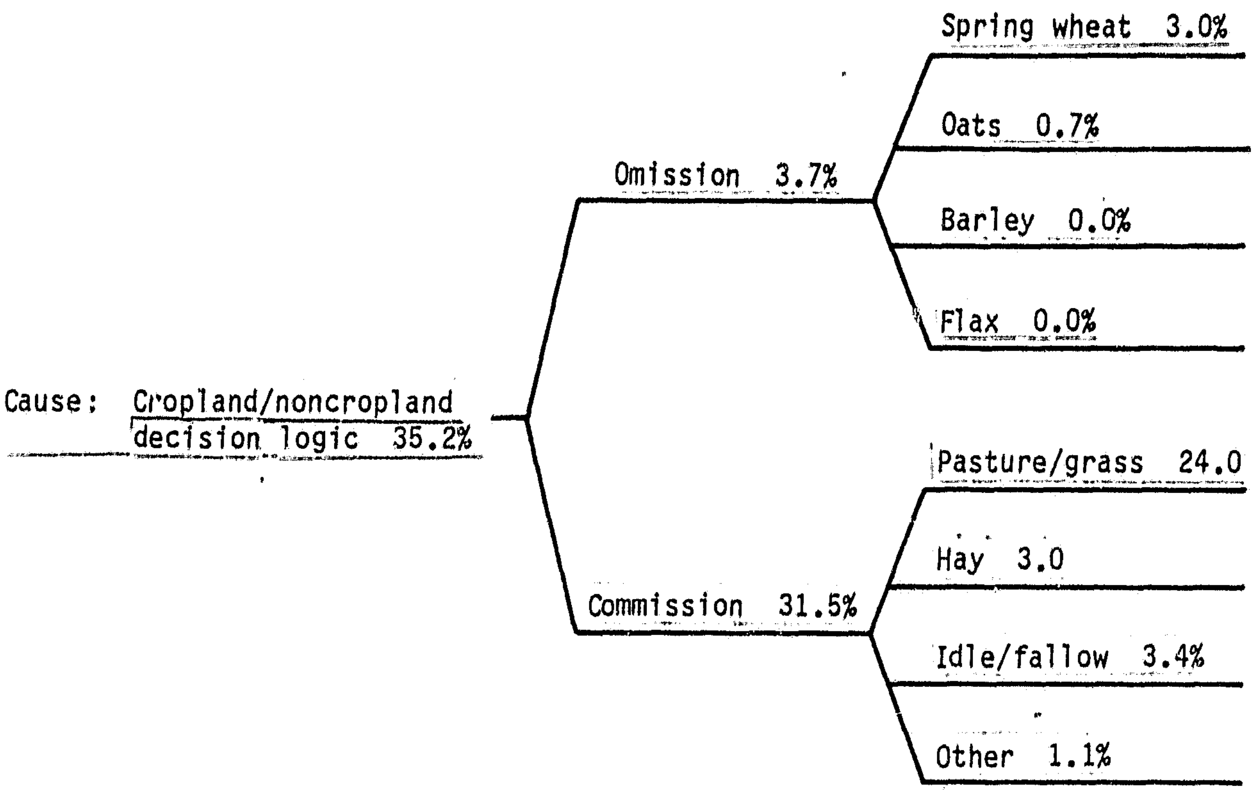
3.1.2.5 Barley/Other Spring Small Grains Error Characterization, Phase 2, Part 2

Four hunderd fifty-four spring small grain dots were labeled correctly as spring small grains by both processings.

3.1.2.5.1 Dots Labeled Incorrectly in Both Processings

Thirty dots (6.6 percent) were mislabeled at the barley and other spring small grains breakpoint in both processings. Table 3-10 indicates the number of mislabeled dots for each crop category according to the cause for mislabeling. Segment 1676 had no errors at this breakpoint. Among the other segments, there was fairly even distribution of the errors. In table 3-10, the barley committed to the spring small grains category and spring small grains committed to the barley category errors almost balance each other (14 versus 16).

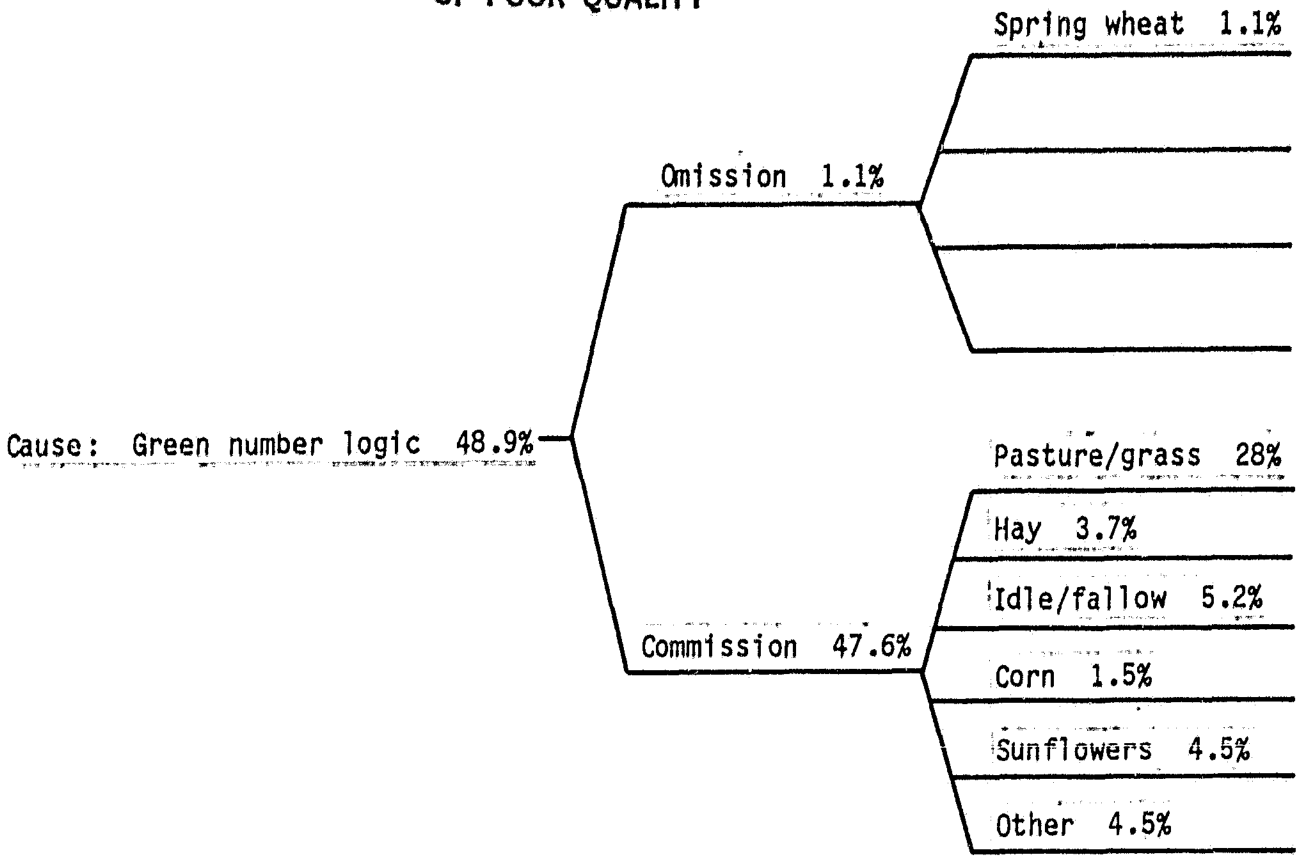
Of additional significance is the fact that 24 out of 30 errors (80 percent) were caused by the dots falling within the wrong spectral distribution in the



The percentage of the errors made when answering each question in the cropland/noncropland decision logic shown in figure 3-1 is given below.

Crop	Question number and percentage of error					
	1A	1B	1C	2	3	4
Spring wheat	1.1		0.8	0.4	0.7	
Oats			0.35		0.35	
Pasture/grass					24.0	
Hay			0.4		2.6	
Idle/fallow			2.4		0.8	
Other				0.4	0.7	
Total	1.1		4.15	0.8	29.15	

Figure 3-6.- Cropland/noncropland decision logic error characterization, single processing, Phase 2, Part 2.



The percentage of the errors made in each window/period is given below.

Crop	Window/period and percentage of errors					
	1	2	3	A	4	All
Spring wheat		0.4		0.4	0.4	
Pasture/grass						28.1
Hay						3.7
Idle/fallow						5.2
Corn						1.5
Sunflowers						4.5
Other						4.5
Total		0.4		0.4	0.4	47.5

Figure 3-7.- Green number decision logic error characterization, single processing, Phase 2, Part 2.

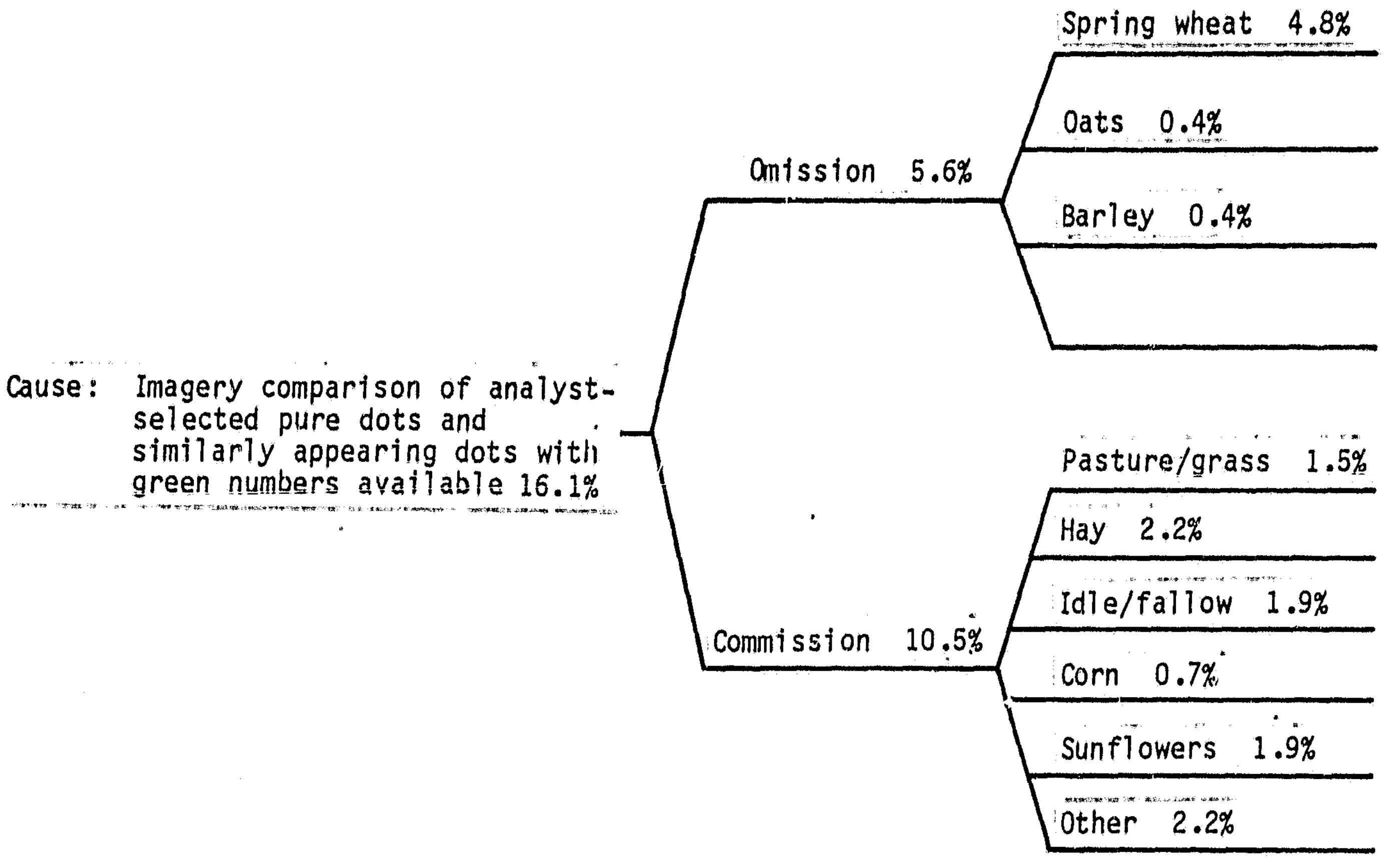


Figure 3-8.- Imagery comparison error characterization, single processing, Phase 2, Part 2.

TABLE 3-10.- NUMBER OF MISLABELED DOTS BY CATEGORY AND CAUSE IN BOTH PROCESSINGS

Cause of mislabeling	Barley committed to the other small grains				Other spring small grains committed to the barley category
	Spring wheat	Oats	Flax	Total	
Direct interpretation	2	0	0	2	0
Decision line	4	0	0	4	0
Early development	2	6	0	8	-
Nonseparation	-	-	-	-	16
TOTAL	8	6	0	14	16

scatter plots. These errors are caused either by early development of spring wheat and oats or by nonseparation of barley from the other spring small grains even with correct application of the procedure.

3.1.2.5.2 Errors Made in Only One Processing

Twenty-eight dots (6.2 percent) of the spring small grain dots were labeled correctly by one analyst and incorrectly by the other analyst at the barley and small grains breakpoint. Table 3-11 indicates the number of mislabeled dots for each crop category according to the cause for mislabeling. Segments 1387, 1627, and 1676 had no errors. Twenty-two errors were in the following segments:

a. Segment 1394: 6 dots, apparent early wheat maturity

b. Segment 1457: 7 dots, no separation of barley
   1 dot, an incorrect interpretation by analyst

c. Segment 1658: 8 dots, apparent early wheat maturity
   1 dot, an incorrect interpretation by analyst

Of significance is the fact that direct analyst interpretation was responsible for eleven (39 percent) of the errors made by a single analyst. Note also that it was this 39 percent that contributed most to the imbalance between the barley commission errors of spring grains and spring grains/barley.

3.1.2.6 Consistency of Labeling Between the Two-Analyst Processings Using the Objective Reformatted Labeling Procedure (SSG-1) in Phase 2, Part 2

For all dots labeled on the nine segments, 78 percent were labeled consistently. (Consistent means that both analysts assigned the same label to a given dot, but not necessarily the correct label.) The accuracy of the dots labeled consistently by both analysts by crop category is in table 3-7. The labeling accuracy for total small grains for the consistently labeled dots averaged 77 percent.

TABLE 3-11.- NUMBER OF MISLABELED DOTS BY CATEGORY AND CAUSE IN ONE PROCESSING

Cause of mislabeling	Barley committed to the other small grains				Other spring small grains committed to the barley category
	Spring wheat	Oats	Flax	Total	
Direct interpretation	10	0	0	10	1
Decision line	2	0	0	2	1
Early development	8	0	0	8	-
Nonseparation	-	-	-	-	6
TOTAL	20	0	0	20	8

3.2 MACHINE PROCESSING/CLASSIFICATION TEST RESULTS

Results of the machine processing/classification test, based upon ground-truth input labels, are:

a. A significant increase in the precision of segment proportion estimates was obtained by CLASSY stratification (table 3-12).

   (1) This was the first time a machine processing technique had performed better than the technique of using simple random sampling and making the proportion estimate by relative count.

   (2) It requires three times as many labeled pixels for a randomly sampled segment in order to achieve the same proportion estimation precision as when CLASSY stratification is used.

b. Segment proportion estimation bias and MSE are significantly reduced by machine processing/CLASSY stratification when compared with the results from random sampling (table 3-12).

c. There is not a significant difference in the performance of the three machine allocation and estimation techniques: (1) proportion allocation/ relative count, (2) proportional allocation/Bayes estimator, and (3) Bayes sequential allocation/Bayes estimator.

Summarized in table 3-12 are the biases of proportion estimates, standard deviations of estimate errors, and MSE's for 35 segments using the four procedures with dot labels from analyst interpreters (integrated procedure) as input. The errors are shown in figure 3-9.

Machine processing/classification test results are in addendum 2, volume II, of this document and also in reference 3.

3.2.1 PROPORTIONAL ALLOCATION/RELATIVE COUNT ESTIMATOR FINDINGS

The proportional allocation/relative count estimator provided a significantly less biased estimate and produced less variable errors than did random sampling. The fact that the errors were less variable indicated that the clustering algorithm had been effective.

TABLE 3-12.- PROPORTION ESTIMATION RESULTS WITH GROUND TRUTH AND ANALYST LABELS

Proportion estimation technique	Ground truth labels			Analyst labels		
	Bias, %	Standard deviation	MSE	Bias	Standard deviation	MSE
Random sample/relative count	-2.5	6.9	53	-5.7	7.7	90
Proportional allocation/ relative count, CLASSY stratification	0.0	4.0	16	-4.0	6.2	53
Proportional allocation/ Bayes estimator, CLASSY stratification	0.5	3.8	14	-3.5	6.0	47
Bayes sequential allocation/ Bayes estimator, CLASSY stratification	0.4	4.7	22	-2.7	6.8	52

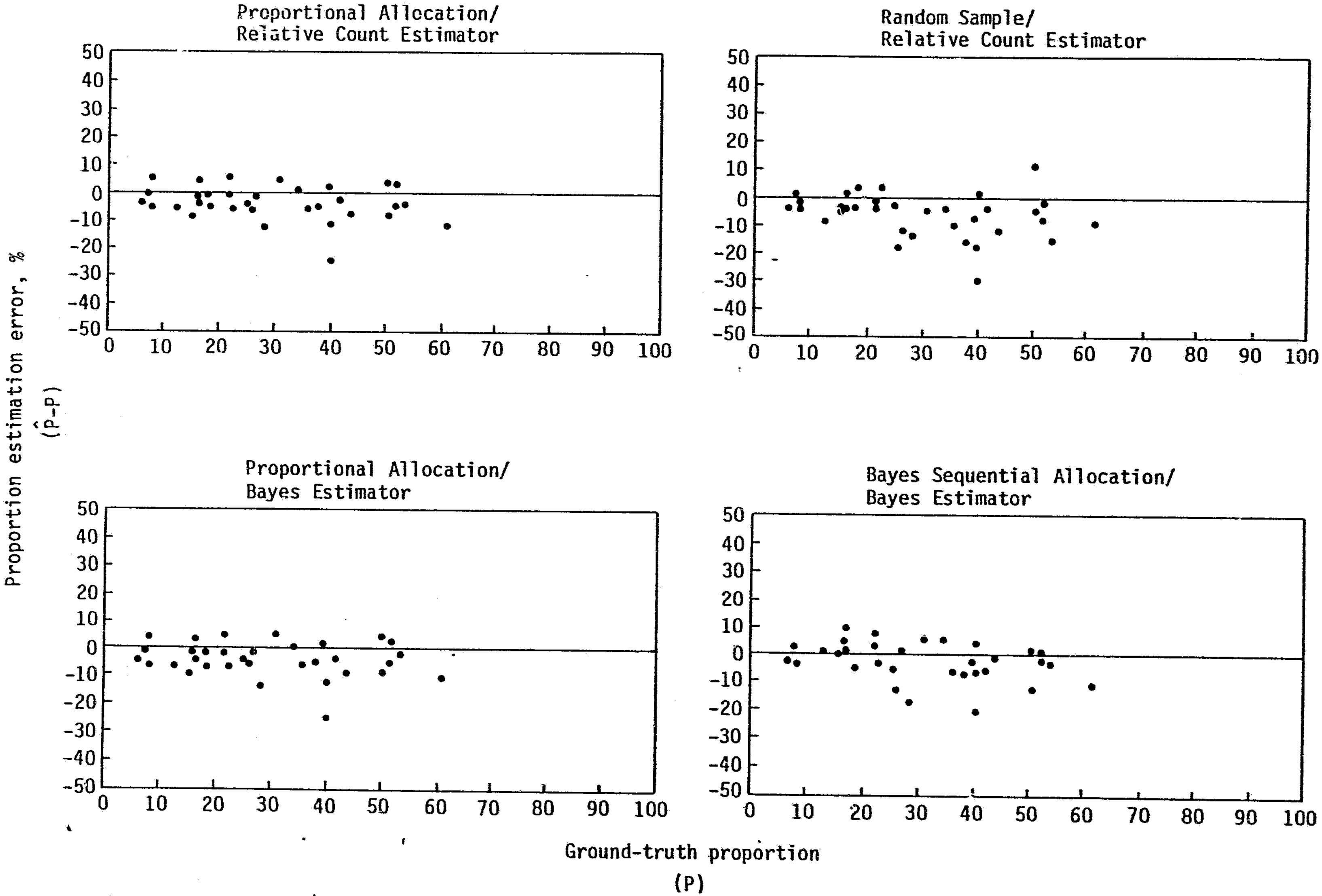


Figure 3-9.- Proportion estimation results with analyst labels.

3.2.2 PROPORTIONAL ALLOCATION BAYESIAN ESTIMATOR FINDINGS

Since clustering was effective, the next step was to determine the effect of a Bayesian estimator. With the proportional allocation/Bayesian estimator, a cluster-level Bayesian estimator was used instead of a vegetative count estimator. It had been hypothesized that the proportional allocation/Bayesian estimator would provide improved proportion estimates over the proportional allocation/relative count estimator because prior knowledge of cluster purities was being considered. As hypothesized, there seemed to be improved precision, but the difference was small (table 3-12). These results were encouraging because they supported the expectation that Bayesian estimation at the cluster level would provide greater precision (although slightly biased results) over maximum likelihood estimation.

3.2.3 BAYESIAN SEQUENTIAL ALLOCATION/BAYESIAN ESTIMATOR FINDINGS

The final technique was the Bayesian sequential allocation/Bayesian estimator. The results showed it to be the least biased technique when analyst interpreter labels were used as input (table 3-12).

This had been hypothesized since the dots were allocated to clusters one at a time, with the intention of minimizing the MSE. Although it produced the least biased results, the Bayesian sequential allocation/Bayesian estimator produced more variable results than did proportional allocation. This was a disturbing observation. That the Bayesian sequential allocation/Bayesian estimator produced more variable results than did the proportional allocation/Bayesian estimator was caused (in part) to a decreased overall labeling accuracy.

Further testing indicated that with a small sample of dots (50), proportional allocation is the sampling method that produces the most precise and reliable estimtes. However, if a large enough sample size were taken, the same precision could be obtained by random sampling without the need of clustering information.

3.2.4 RECOMMENDATIONS FOR MACHINE PROCESSING/CLASSIFICATION

While automatic labeling would provide large samples at relatively low costs, it is only a goal. With large samples, these clustering procedures do not seem to provide much improvement in proportion estimation. However, it is not recommended that effective clustering algorithms be discarded. Neither should efforts in proportion estimation techniques be defaulted to random sampling. An effective procedure using clustering information is available for use in testing and for future development. It should be noted that automatic labeling has only recently been developed. It is therefore recommended that these proportion estimation techniques be maintained, particularly the proportion allocation/Bayesian estimator, because it provided the greatest precision.

A recommendation from this exploratory experiment was that the proportion allocation/Bayesian estimator estimation procedure be considered the baseline for the 1981-1982 Spring Small Grains Pilot Experiment. Further exploratory testing needs to be conducted for other crops of interests such as corn and soybeans.

3.3 CROP DEVELOPMENT STAGE MODEL TEST - SUMMARY

The result from the test of planting date models follows: the Feyerherm model is significantly better than the normal model for predicting both spring wheat and barley planting dates (figures 3-10 and 3-11, respectively).

Results from the test of the wheat phenological development stage models are:

a. There are no significant differences between the three models (original Robertson and the two improved versions) in estimating the development stages from tillering to ripening.

b. The improved Robertson models, versions 1 and 2, appear to estimate the late heading and ripening stages of wheat more accurately than the original Robertson model.

The result from the test of the barley phenological development stage models follows: the Robertson spring wheat models performed better than the Williams

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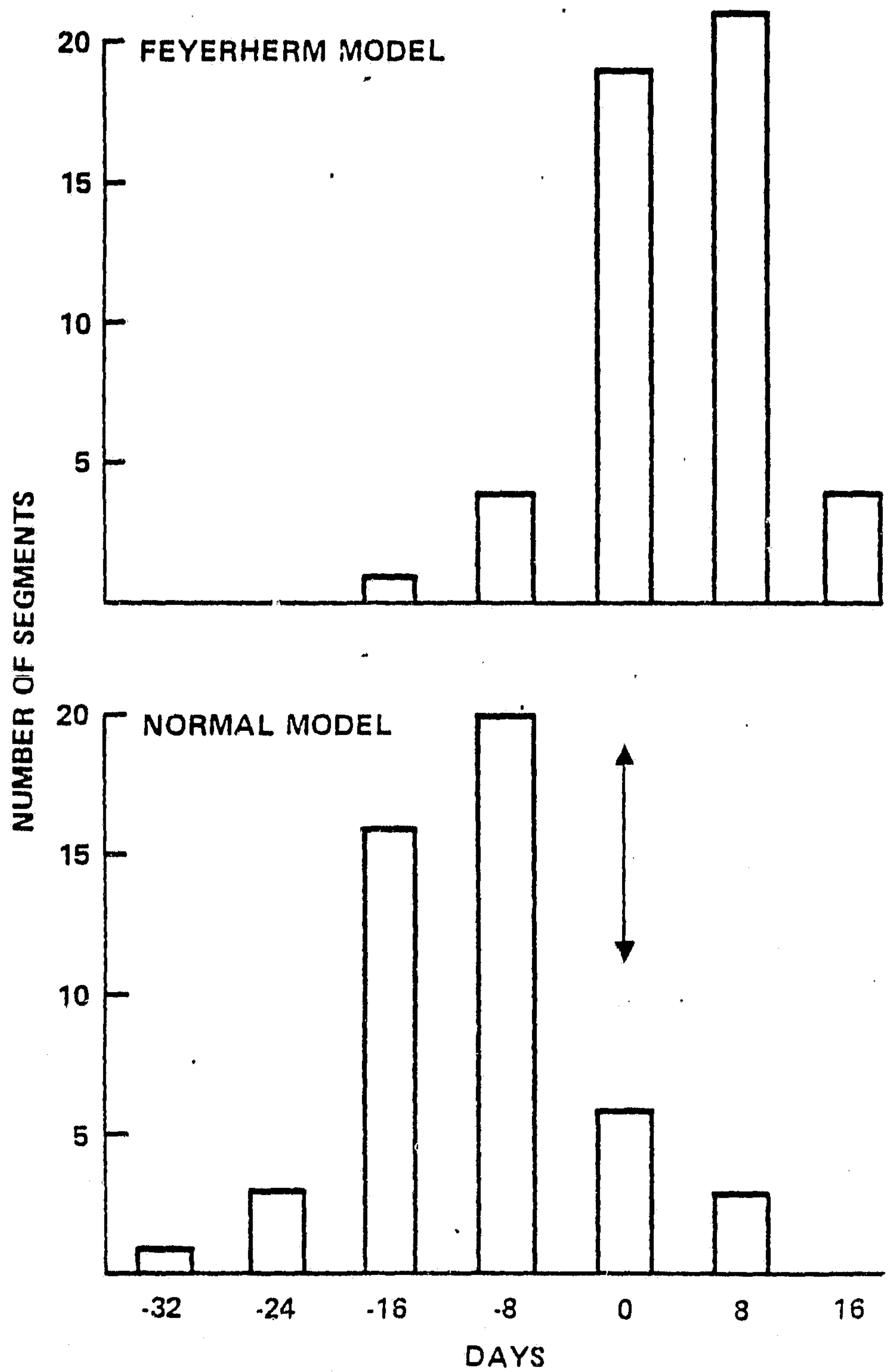

Figure 3-10.- An illustrated comparison of the Feyerherm and normal models for predicting spring wheat planting dates.

PLANTING DATE MODEL RESULTS FOR BARLEY

+ OVERALL STATISTICS INDICATE THAT FEYERHERM IS CLOSER TO THE GROUND TRUTH THAN THE NORMAL IN PREDICTING BARLEY PLANTING DATES.

DISTRIBUTION OF ERRORS (IN DAYS) FOR THE FEYERHERM VS. THE NORMAL PLANTING DATE MODELS APPLIED TO BARLEY

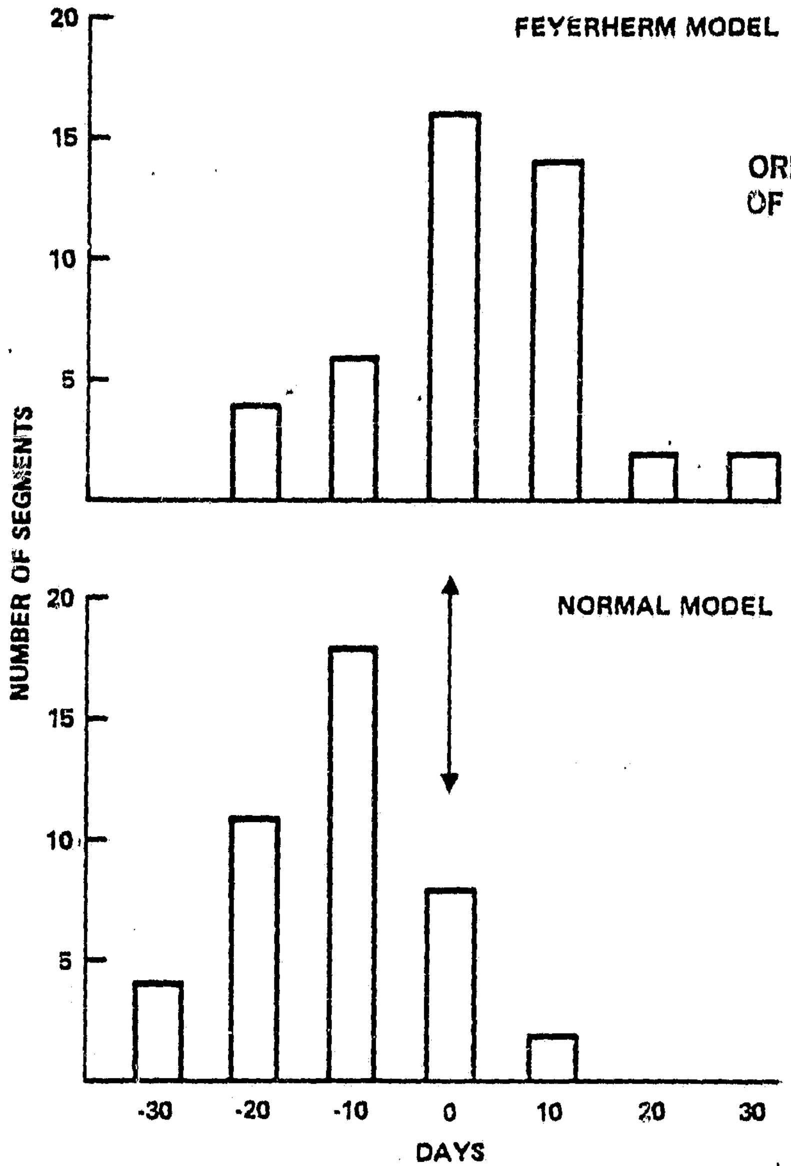

Figure 3-11.- An illustrated comparison of the Feyerherm and normal models for predicting barley planting dates.

barley model. None of the models predicted the wheat/barley separation period very accurately.

3.3.1 DETAILED RESULTS FOR PLANTING DATE MODELS

Both the Feyerherm and the normal models produce median planting date estimates at the segment level. The performances of the models for the spring wheat fields and the barley fields were evaluated separately.

A histogram of the distribution of errors, measured in days for the Feyerherm versus the normal planting date models applied to spring wheat fields, gives an indication of the bias associated with the models. Both distributions appeared normal, the differences being the locations of the midpoints of these distributions. The Feyerherm model has a positive displacement, whereas the normal model has a negative displacement. This indicates that the normal model is very early compared to the ground-truth median planting dates, whereas the Feyerherm model is slightly late. (Based on reports jointly published by the USDA and National Oceanic and Atmospheric Administration of the USDC in the Weekly Weather and Crop Bulletin, the 50 percent planting date of spring wheat in North Dakota for 1979 was 13 days late. Thus, the normal model performed as expected.)

The statistics on the errors, measured in days for the Feyerherm model versus the normal model applied to spring wheat, are summarized in table 3-13. The sign test shown is based on the absolute magnitude of the error and gives the percent of times one model is closer to the ground truth than the other model. Table 3-13 indicates that, on the average, the Feyerherm model is 3.9 days late compared to the observed planting date, whereas the normal model is, on the average, 10.4 days early compared to the observed planting date. Statistically, the sign test indicates that the Feyerherm model is significantly better than the normal model at the 6-percent level of significance. The overall statistics indicate that the Feyerherm model is closer to the ground truth than the normal model in predicting spring wheat planting dates for the year.

TABLE 3-13.- COMPARISON OF ERRORS IN PLANTING DATE MODELS
APPLIED TO SPRING WHEAT FIELDS

	Feyerherm model	Normal model
Number of segments (n)	49	49
Mean error (in days)	+3.9	-10.4
Standard deviation (in days)	7.0	7.50
Median error (in days)	+4.0	-11.0
Sign test (%)	75.5	22.4
(2% tied)		

For the distribution of error, measured in days for the Feyerherm versus the normal planting date models applied to barley fields, both distributions appear normal. However, the Feyerherm model midpoint has a positive displacement, whereas the normal model has a negative displacement. This indicates that the two models are, on the average, late and early compared to the ground-truth median planting dates, as seen for barley fields.

The statistics on the error, measured in days from the Feyreherm model versus the normal model applied to barley fields, are summarized in table 3-14. Note that, on the average, the Feyerherm model is 2.9 days later than the observed planting date, whereas the normal model is, on the average, 10.9 days earlier

TABLE 3-14.- COMPARISON OF ERRORS IN PLANTING DATE MODELS
APPLIED TO BARLEY FIELDS

	Feyerherm model	Normal model
Number of segments (n)	44.0	44.0
Mean error (in days)	+2.9	-10.9
Standard Deviation (in days)	11.48	9.55
Median error (in days)	+4.5	-11.5
Sign test	63.6	36.4

than the observed planting date. The sign test indicates that the Feyerherm model is better than the normal model, though not statistically significant at the 5-percent level of significance. The overall statistics indicate that, for this year, the Feyerherm model is better than the normal model for predicting barley planting dates. Addendum 3 in volume II of this document contains detailed information pertaining to the results for planting date models.

3.3.2 APPROACH FOR EVALUATION OF CROP DEVELOPMENT STAGE MODELS

The three Robertson models and the Williams barley model were started using the ground-truth median planting dates for spring wheat and barley fields as input to the models. They were evaluated on their ability to accurately predict median crop development stages for spring wheat and barley between stages 2.0 and 6.0, which are the emergence through ripe stages.

In an attempt to determine if the models performed differently during various periods of the growing season, the models were evaluated at five ranges of the growth stages as shown below.

1. Stage 2.0 to 2.9: emergence to prejointing
2. Stage 3.0 to 3.9: jointing to preheading
3. Stage 4.0 to 4.9: heading to presoft-dough
4. Stage 5.0 to 5.9: soft-dough to preripening
5. Stage 6.0: ripe

In addition, the overall performance was tested for the entire growing season from stage 2.0 to stage 6.0.

3.3.3 CROP DEVELOPMENT STAGE MODEL RESULTS APPLIED TO SPRING WHEAT FIELDS

Figure 3-12 contains scatter plots of the median-predicted development stages versus the observed median development stages for models R0, R1, and R2. The letters represent the number of data points falling on the character (A = 1, B = 2, etc.). The common trend on all three plots is for the predicted growth stage to converge on the 1-1 line, indicating that the performance of all three models is improving with time through the growing season. In figure 3-12, one can see that model R0 is progressing faster than models R1

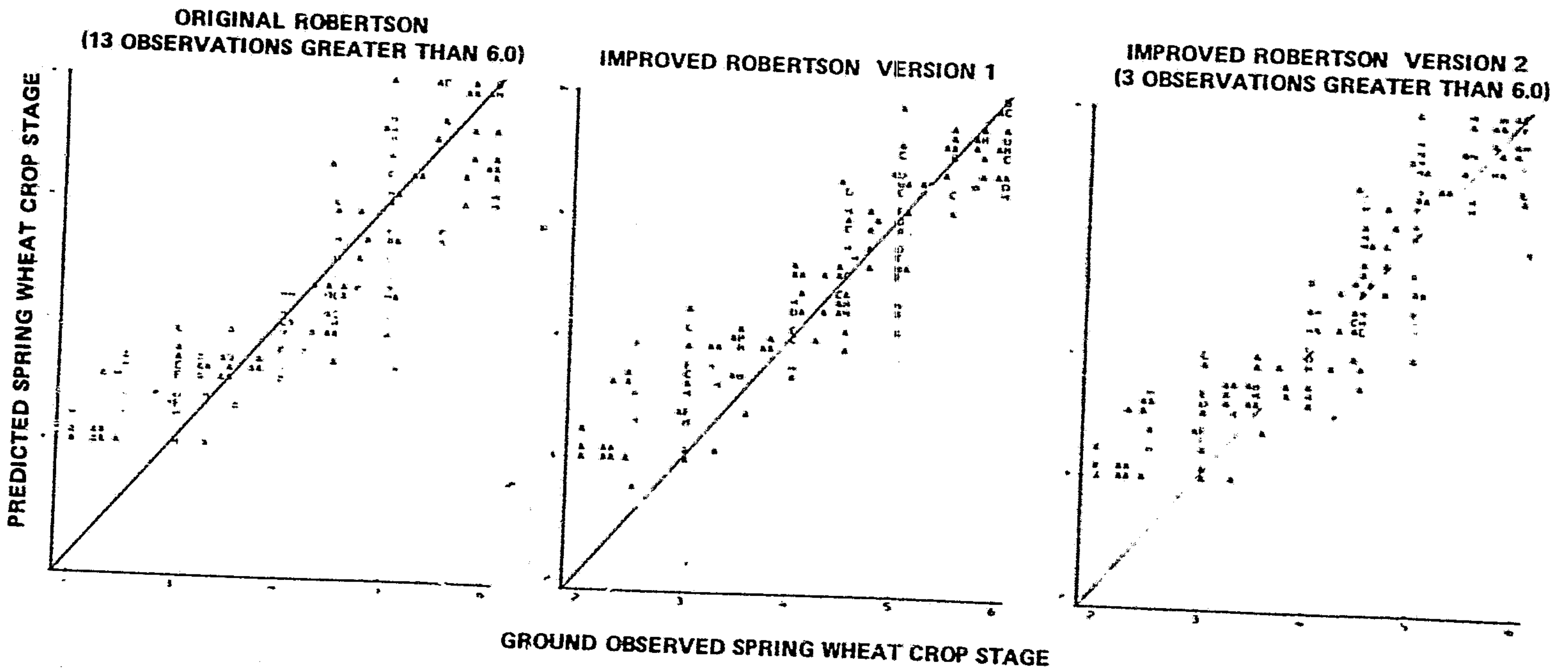

Figure 3-12.- Scatter plots of predicted versus ground-observed spring wheat crop stages for the three spring wheat crop stage models.

and R2 by noting that 13 ground-truth observations are off-scale and greater than stage 6.0 (i.e., swathed and harvested).

The statistics on the errors between the observed stages and the predicted stages that were applied to spring wheat at various intervals throughout the growing season are summarized in table 3-15. The errors are the differences between the predicted stages and the observed stages and should give an indication of the amount of bias associated with each of the models. An average positive error would indicate that the model is ahead of the ground truth, whereas an average negative error would indicate that the model was behind the ground truth. In addition, the absolute value of the error was ranked on a scale of 1 to k, where k is the number of models being compared with each other (in table 3-15, k = 3). The sum of the various ranks associated with each model was then utilized in a Friedman nonparametric test of ranks (ref. 30) to determine if any one model produced better results consistently.

Table 3-15 shows that there were no significant differences between any of the three models when evaluating the overall performance from ground-truth stages 2.0 to 6.0. The range of the mean error for the three models was two-tenths of a stage, and the Friedman T-statistic indicates that there is no significant difference between the models at the 95-percent confidence level.

For stages 2.0 to 2.9, there was a marginal difference between the three models. It is apparent that R1 is the worst performer of the three models at this stage interval, as indicated by the statistics on the errors and the observed sum of the ranks. From stages 3.0 to 3.9, there was a significant difference between the models. Model R0 appeared to be the best at this stage interval. From stages 4.0 to 4.9, there was no significant difference between the models. For stages 5.0 to 5.9, there was a significant difference between the models, and R1 appeared to perform the best within this stage interval. Finally, at stage 6.0, there was a significant difference between the three models. Model R2 appeared to perform the best of the three models. At ground-truth stage 6.0, the mean and standard deviation have not been

TABLE 3-15.- COMPARISON OF ROBERTSON MODELS APPLIED TO SPRING WHEAT

Ground-truth range	Statistic	Robertson 0	Robertson 1	Robertson 2
2.0 - 6.0 Entire growing season	Mean error	0.0	0.2	0.2
	STD	0.53	0.48	0.46
	Median error	0.0	0.1	0.2
	ΣRank observed	100.21	97.08	96.71
	Friedman's T-statistic: 0.15 (not significant)			
2.0 - 2.9	Mean error	0.9	1.0	0.9
	STD	0.25	0.28	0.25
	Median error	0.9	1.0	0.9
	ΣRank observed	25.00	37.75	27.25
	Friedman's T-statistic: 6.17 (significant)			
3.0 - 3.9	Mean error	0.3	0.7	0.4
	STD	0.26	0.32	0.26
	Median error	0.3	0.7	0.4
	ΣRank observed	42.42	95.25	66.33
	Friedman's T-statistic: 41.17 (significant)			
4.0 - 4.9	Mean error	-0.2	0.1	0.1
	STD	0.26	0.27	0.31
	Median error	-0.2	0.1	0.0
	ΣRank observed	89.67	70.75	79.58
	Friedman's T-statistic: 4.48 (not significant)			
5.0 - 5.9	Mean error	-9.2	0.0	0.1
	STD	0.42	0.27	0.33
	Median error	-0.2	0.0	0.2
	ΣRank observed	109.45	66.60	93.95
	Friedman's T-statistic: 20.92 (significant)			
6.0	Mean error	--	--	--
	STD	--	--	--
	Median error	-0.5	-0.4	-0.3
	ΣRank observed	50.0	48.4	33.5
	Friedman's T-statistic: 24.07 (significant)			

At 95-percent confidence level, Friedman's T-statistic critical value = 5.99.
At 99-percent confidence level, Friedman's T-statistic critical value = 9.21.

displayed, as they are not valid. The observations obtained beyond stage 6.0 were beyond the range of the model's abilities of prediction and, therefore, were not valid.

3.3.4 CROP DEVELOPMENT STAGE MODEL RESULTS APPLIED TO BARLEY FIELDS

Figure 3-13 contains scatter plots of the median-predicted development stage for model R2 and the Williams barley model versus the observed median development stage. The letters represent the number of data points falling on that character. At first glance, there is no apparent difference between the two models, although the barley model appears to be more dispersed about the 1-1 line than model R2. More significant is the fact that 33 observations are beyond 6.0, indicating that the barley model is progressing faster than the spring wheat model.

In table 3-16 are the statistics on the errors between the median ground-truth stage and the model-predicted median stage applied to barley at various stage intervals through the growing season. Table 3-16 indicates that there was a significant difference between the models for the overall performances from stages 2.0 to 6.0. The barley model is significantly worse than at least one of the spring wheat models.

From stage 2.0 to 2.9, there were marginal differences between the models. Model R0 appeared to perform the best of the four models as indicated by the error statistics and the observed sum of the ranks. For stages 3.0 to 3.9, there was a significant difference between the models. Model R0 appeared to be the best of the four models. From stages 4.0 to 4.9, there were no significant differences between the models. They appeared to be nearly identical at this stage interval. For stages 5.0 to 5.9, there was a significant difference between the models. Model R1 appeared to perform the best. At stage 6.0, there were no significant differences between the models, and model R2 appeared to perform the best.

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TABLE 3-16.- COMPARISON OF ROBERTSON AND WILLIAMS MODELS APPLIED TO BARLEY

Ground-truth range	Statistic	Robertson 0	Robertson 1	Robertson 2	Williams barley
2.0 - 6.0 Entire growing season	Mean error	-0.2	0.0	0.0	0.4
	STD	0.67	0.60	0.61	0.60
	Median error	-0.2	0.0	0.0	0.0
	ΣRank observed	117.67	96.96	98.58	126.79
	Friedman's T-statistic: 8.74 (significant)				
2.0 - 2.9	Mean error	1.0	1.1	1.0	1.2
	STD	0.32	0.37	0.33	0.35
	Median error	1.1	1.2	1.1	1.2
	ΣRank observed	22.33	33.50	24.67	39.50
	Friedman's T-statistic: 9.49 (significant)				
3.0 - 3.9	Mean error	0.3	0.4	0.4	0.6
	STD	0.32	0.38	0.36	0.42
	Median error	0.2	0.4	0.3	0.5
	ΣRank observed	50.58	90.67	65.08	113.67
	Friedman's T-statistic: 43.79 (significant)				
4.0 - 4.9	Mean error	-0.3	-0.1	-0.2	0.1
	STD	0.32	0.34	0.38	0.52
	Median error	-0.3	0.0	-0.1	0.2
	ΣRank observed	89.42	62.67	74.92	79.0
	Friedman's T-statistic: 7.18 (not significant)				
5.0 - 5.9	Mean error	-0.5	-0.3	-0.2	0.1
	STD	0.57	0.45	0.54	0.59
	Median error	-0.6	-0.2	-0.2	0.3
	ΣRank observed	129.93	70.67	95.10	114.30
	Friedman's T-statistic: 28.68 (significant)				
6.0	Mean error	--	--	--	--
	STD	--	--	--	--
	Median error	-0.9	-0.7	-0.6	>0.0
	ΣRank observed	48.0	35.0	26.5	50.5
	Friedman's T-statistic: 14.31 (significant)				

At 95-percent confidence level, Friedman's T-statistic critical value = 7.82.
At 99-percent confidence level, Friedman's T-statistic critical value = 11.34.

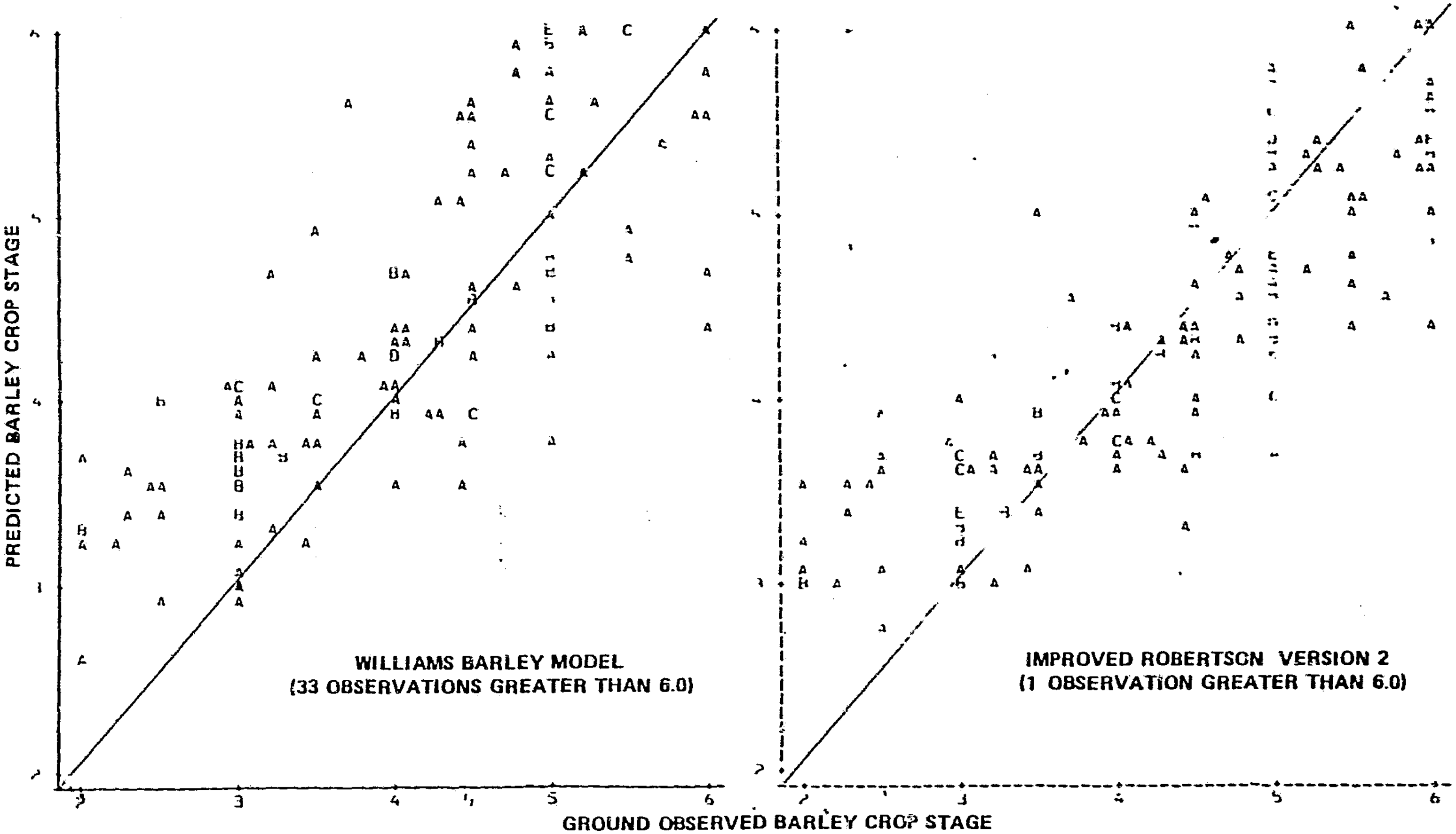

Figure 3-13.- Scatter plots of predicted versus ground-observed barley crop stages for Williams barley model and the improved Robertson, version 2, spring wheat model.

3.3.5 RECOMMENDATIONS FROM CROP DEVELOPMENT STAGE MODEL TESTS

Based on the results to date, it is recommended that the Feyerherm planting date model be utilized for both spring wheat and barley. It appears that the improved Robertson model, version 2, is the more useful for predicting spring wheat and barley development stages. However, the model is not adequate to determine window 3 of the reformatted procedure, which is used to separate barley from spring wheat. Further research on biowindow 3 is required if accurate results are to be obtained for identifying this window.

4. CONCLUSIONS AND RECOMMENDATIONS

The spring small grains labeling procedures evaluation results are listed below.

a. Reformatted labeling (SSG-1) results are comparable to those of the integrated analysis procedure SSG-0.

b. The SSG-1 procedure is conducive to automation.

c. Error sources in the SSG-1 procedure are easily identified and quantified due to the tree-structured design of the procedure.

d. Improvements to the SSG-1 labeling logic are required to eliminate the confusion of pasture and spring small grains.

e. Additional criteria for defining acceptable SSG-1 Landsat acquisitions for processing are required.

f. Labeling is consistent using the reformatted SSG-1 labeling procedure.

The results from the SSG-1 wheat/barley separation evaluation follow:

a. Labeling accuracy was approximately 50 percent in low-density barley segments.

b. Because high-density barley segments were not available, the procedure was not adequately evaluated.

c. Crop development stage models were insufficient for selecting the wheat/barley separation acquisition.

The machine processing/classification procedure results indicate the following.

a. CLASSY stratification improved the precision of the proportion estimation procedures.

b. Estimation bias and MSE were significantly reduced over random sampling for the first time ever.

The crop development stage model test results indicate the following.

a. The Feyerherm planting date model performs better than the normal model for both spring wheat and barley.

b. The performance of all three versions of the Robertson spring wheat model is similar.

c. The performance of the Robertson and Feyerherm models appears to be satisfactory for integration into automated labeling procedures; however, further evaluation is recommended.

In summary, the results of the exploratory experiment indicate it to be a strong potential for establishing the basis for a highly efficient technology for evaluation in a foreign environment.

Three recommendations follow:

1. A pilot experiment on spring small grains in the USNGP and Canada should be conducted to further develop, test, and evaluate the technology prior to initiating a foreign pilot experiment.

2. The technology focus should be directed towards techniques for efficient area estimation and procedures for sensitivity analysis of spring small grain area estimation.

3. The expected assessment performance in foreign countries should be considered.

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